

NOVEMBER, 1958

DENTAL CLINICS
of
NORTH AMERICA

SYMPOSIUM ON

*Dental Materials—Their Use and
Recent Developments*

RALPH W. PHILLIPS, M.S.
CONSULTING EDITOR

W. B. SAUNDERS COMPANY

Philadelphia & London

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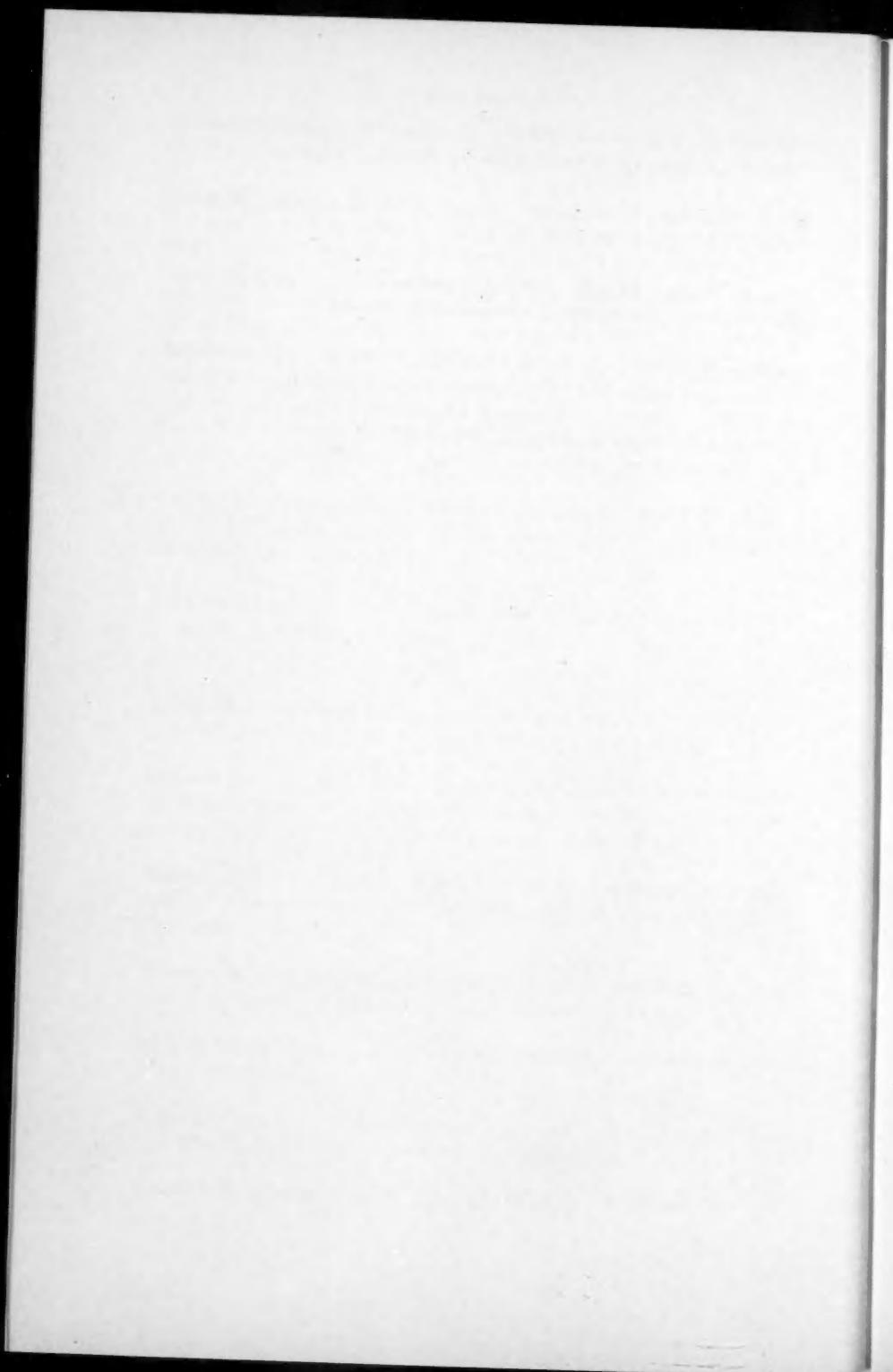
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Contents

SYMPOSIUM ON DENTAL MATERIALS—THEIR USE AND RECENT DEVELOPMENTS

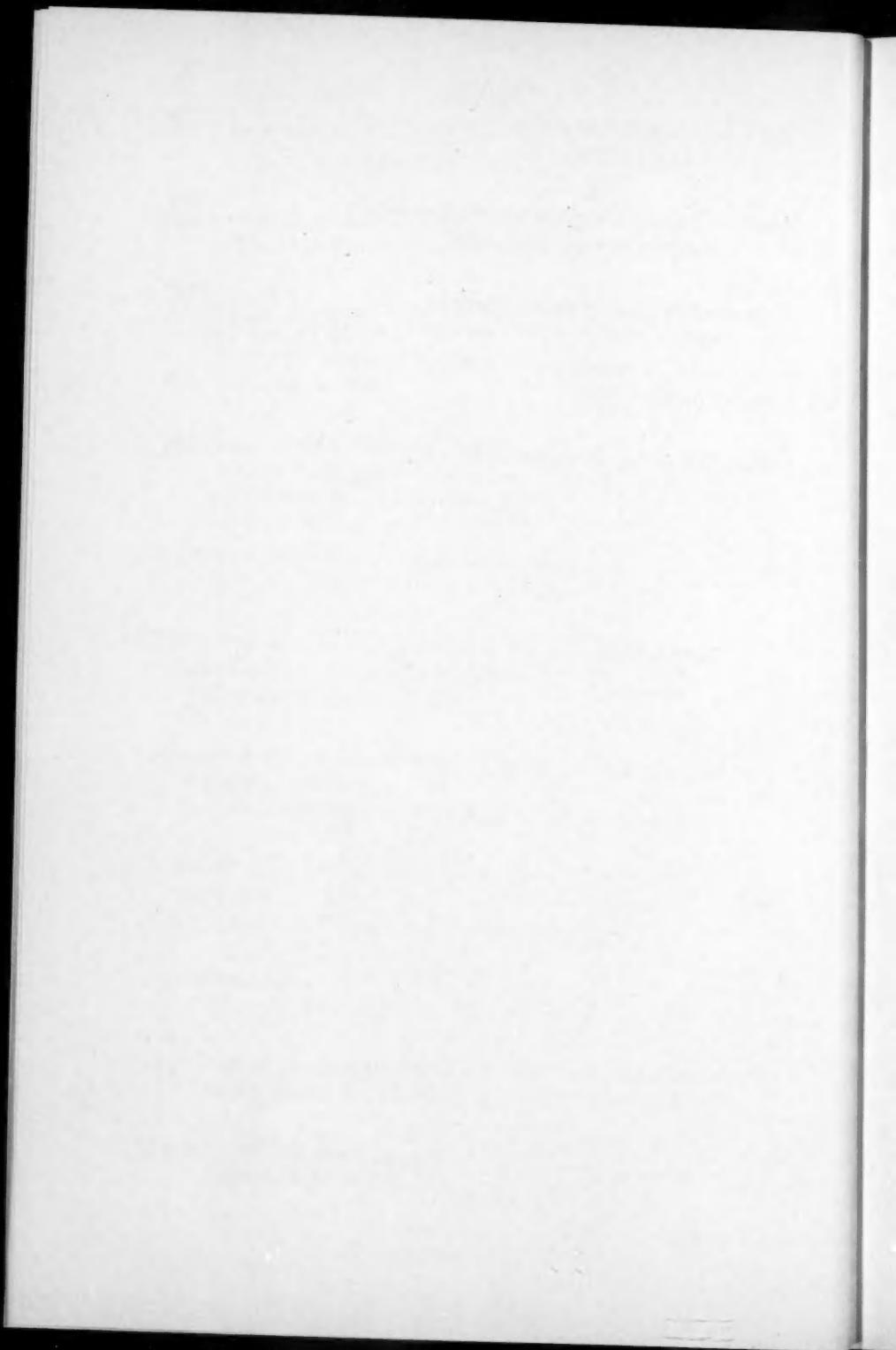
<i>Foreword by</i>	545
RALPH W. PHILLIPS, M.S. CONSULTING EDITOR	
<i>Amalgam</i>	547
RALPH W. PHILLIPS, M.S.	
<i>Zinc Phosphate and Silicate Cements</i>	561
GEORGE C. PAFFENBARGER, D.D.S., AND JOHN W. STANFORD, B.S., M.S.	
<i>Correlation of Physical Properties and Clinical Aspects of Gold Foil as a Restorative Material</i>	571
CHARLES M. STEBNER, D.D.S.	
<i>An Evaluation of Cavity Liners and Intermediate Base Materials</i>	585
JOHN H. MOSTELLER, D.D.S.	
<i>Acrylic Resins in Prosthetic Dentistry</i>	593
W. T. SWEENEY, A.B.	
<i>Self-curing Resins in Restorative Dentistry</i>	603
DREXELL A. BOYD, D.D.S.	

<i>The Wax Pattern</i>	615
MILES R. MARKLEY, D.D.S.	
<i>Hygroscopic Investment Expansion for Small Castings</i>	625
HERBERT D. COY, D.D.S., AND S. GUY HALL, D.D.S.	
<i>Use of Gold Alloys in Small Castings and Thermal Expansion Techniques</i>	637
ROBERT E. SAUSEN, D.D.S., M.S.D., AND HUBERT H. SERR, D.D.S., M.A.	
<i>The Veneered Gold Crown</i>	653
ROLAND W. DYKEMA, D.D.S., JOHN F. JOHNSTON, D.D.S., AND DONALD M. CUNNINGHAM, D.D.S.	
<i>Impression Materials in Prosthetic Dentistry</i>	671
WILLIAM L. McCACKEN, D.D.S., M.S.	
<i>The Properties and Manipulation of Mercaptan Base and Silicone Base Impression Materials</i>	685
EUGENE W. SKINNER, PH.D.	
<i>Mercaptan Rubber Impression Technique for Single and Multiple Restorations</i>	699
CLIFFORD M. STURDEVANT, D.D.S.	
<i>Reversible and Irreversible Hydrocolloid Impression Materials</i>	713
STANLEY D. TYLMA, A.B., D.D.S., M.S.	
<i>Plaster and Stone</i>	727
ALLAN R. DOCKING, M.Sc.	
<i>Modern Rotating Instruments—Burs and Diamond Points</i>	737
JACK L. HARTLEY, D.D.S., AND DONALD C. HUDSON, D.D.S.	
<i>Dental Soldering Procedures</i>	747
GUNNAR RYGE, D.D.S., M.S.	

CONTENTS

ix

<i>Cast Chromium-Cobalt Alloys</i> F. A. PEYTON, D.Sc.	759
<i>Stainless Steels in Dentistry and Orthodontics</i> J. WILLIAM ADAMS, D.D.S., M.S.	773
<i>Analysis of Stress in Dental Structures</i> DAVID B. MAHLER, PH.D., AND LOUIS G. TERKLA, D.M.D.	789
<i>Index of Authors, 1958</i>	799
<i>Cumulative Index, 1957 and 1958</i>	801



SYMPOSIUM ON DENTAL MATERIALS— THEIR USE AND RECENT DEVELOPMENTS

Foreword

Dental research, and thus dental science, is moving at an accelerated pace. Probably no other area has enjoyed such far-reaching advances as has the field of dental materials. Almost phenomenal progress has been made during the last decade in all materials and techniques; yet, if one visualizes the eventual application in dentistry of the research activities in the basic science fields of chemistry, physics and metallurgy, the immediate horizon is filled with possibilities which defy the imagination. Our concepts, theories, research programs and practice of dentistry must, and most certainly will, change with these technical advances. It is to this end that much of the organization of this issue of the *Dental Clinics* was directed.

The reader, I am sure, realizes that the responsibility of evaluating all the newer materials and technics as well as recent research on the older, established materials is most formidable. Space limitations prevent a comprehensive discussion of any one material or technic or even an analysis of the newer research tools which offer tremendous opportunities to the laboratory or clinical investigator. The topics discussed were chosen because it was felt that they would encompass the materials most commonly used, were of greatest general interest and were possibly the most controversial. The authors were chosen because each is an outstanding and respected authority on his subject.

This symposium should not be regarded as a text in dental materials. Rather, its purpose is twofold: (1) to bring the reader abreast of current developments and concepts in this field and (2) to relate the basic physical and chemical properties of the material with its clinical behavior. The contributors have made a sincere effort to present a concise and accurate appraisal of the newer advances, untarnished by prejudice or commercial interests. It is to be hoped that some of the confusion, and accompanying frustration, associated with some of these materials and technics can be resolved in these pages. Likewise, the inherent properties of the materials and their clinical relationship are continually stressed. One cannot be in sympathy with any attempt

made to divorce the science of dental materials from its clinical application. This relationship is practical, dynamic and fundamental to successful dentistry.

The perfect restoration or ideal dental material has not yet been developed and thus it is to be admitted that selection and improvements of any material are dependent upon recognition of its good and bad inherent characteristics. Conditions in the oral cavity are heroic and unique. The problems of pH and temperature change, the high stresses brought to bear on the appliance, considerations of the hard and soft tissues and of lasting esthetics are only a few of the factors which serve to emphasize the need for cooperation between the dentist and workers in all the basic sciences. This cooperation must be based upon mutual appreciation of the scope and problems that characterize these various fields of endeavor. The manufacturer, research worker or dentist can no longer divorce the bacteriologic, pathologic or biochemical considerations from the basic chemical or metallurgical properties of the material itself. This, then, constitutes the changing science of dental materials.

There can be no doubt that certain of the observations made here may shortly be obsolete. For just one example, the use of radioactive tracers is rapidly altering our concepts in regard to the ability of restorative materials to seal the cavity preparation. Microleakage appears to be an ever-present hazard with all materials, and as this research unfolds, changes in materials and technics to provide better adaptation and increased bacteriostatic characteristics may be anticipated. Many other examples could be cited to illustrate how newer laboratory tools and the investigations now in progress will most certainly prevent the field from long remaining static. However, at the moment the evaluations by the experts in each field are certainly valid.

I would like to acknowledge the unqualified cooperation of each contributing author, without which this symposium could not have been possible. Likewise, and speaking for the contributors as well, recognition must be given to the vast army of research workers, both laboratory and clinical, from whose contributions these articles have been drawn.

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Amalgam

RALPH W. PHILLIPS, M.S.*

There is no doubt that with conscientious use amalgam is an excellent filling material. All restorative materials have certain advantages and disadvantages and the dentist should be more concerned with the factors which influence the clinical success of each material than with arguing the respective merits of the individual type. Brekhus and Armstrong¹ observed that not only was amalgam the most frequently used material in restorative dentistry but also there was a lower percentage of failures in restorations made with amalgam than with any of the other restorative materials. However, daily observations in the dental office do reveal many amalgam failures. These failures result from (1) recurrent caries, (2) fracture, (3) dimensional change and (4) excessive tarnish and corrosion.⁶

With the adoption of American Dental Association Specification No. 1, few inferior dental alloys are now marketed; hence, the observed amalgam failures must be attributed to factors other than the material itself. The success of the amalgam restoration is dependent upon control of, and attention to, many variables. Each manipulative variable from the time that the cavity preparation is made until the restoration has been polished has a very definite effect upon the physical properties and the success or failure of the restoration. One investigation⁶ has shown that improper cavity preparation is the causative factor in approximately 56 per cent of all amalgam failures, while faulty manipulation of the alloy, or its contamination at the time of insertion, accounts for approximately 40 per cent of all failures. It is thus apparent that not only is proper adherence to fundamentals in cavity preparation essential, but also that careful standardization of all manipulative factors is imperative.

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PERTINENT PHYSICAL PROPERTIES

The three basic properties of amalgam which must be given consideration are dimensional change, compressive strength, and flow. Proper control of all three of these properties is essential if clinical failure is to be avoided. A proper understanding of these properties and, more important, their clinical significance is necessary in order to appreciate the importance of the various manipulative factors which will be discussed.

Dimensional Change

Dimensional change in the restoration after its insertion should, of course, be at a minimum. The A.D.A. specification for amalgam states that 24 hours after its insertion the alloy should have expanded between 3 and 13 microns per centimeter. Although slight deviations from these limits are apparently not clinically significant, changes of greater magnitude can lead to disastrous results.

Compressive Strength

There is no doubt that adequate compressive strength is essential to the success of the amalgam restoration. Fracture, even on a small area, or fraying of the margins will hasten recurrence of decay and subsequent clinical failure. The requirement for compressive strength has been deleted from the A.D.A. specification because most amalgam alloys which pass the flow test also meet the compressive strength requirement of 35,000 lbs. per square inch after 24 hours. This specification is soon to be reinstated with a higher minimum value as well as a one hour requirement. Daily observations in the dental office do reveal many fractured amalgam restorations, approximately 26 per cent of all failures being attributed to fracture.⁶ These fractures are associated with either (1) improper cavity preparation, which is usually due to inadequate bulk of material, or (2) faulty manipulation of the material.

Research has clearly shown that various manipulative factors such as improper condensation can drastically lower the crushing strength.^{5,10,12,13} Consequently, it must be emphasized that not only is it necessary to have proper cavity preparation in order to provide adequate bulk of material, but also an exact manipulative procedure must be carried out if maximum strength is to be maintained.

It is highly desirable not only that the compressive strength be great at the end of 24 hours, but also that the alloy gain this strength quite rapidly. Unfortunately, amalgam is quite weak during the first few

hours (Fig. 1), generally at one hour having attained only 10 or 15 per cent of its eventual maximum strength. The exact amount of strength necessary to resist fracture during mastication is not known but certainly 8,000 lbs. per square inch is most inadequate. This inherent weakness in the material thus indicates the necessity of warning the patient to avoid excessive biting forces during the first few hours after insertion of the restoration. The recommendation of a liquid diet for the next meal is probably a sound one. Even with careful cavity

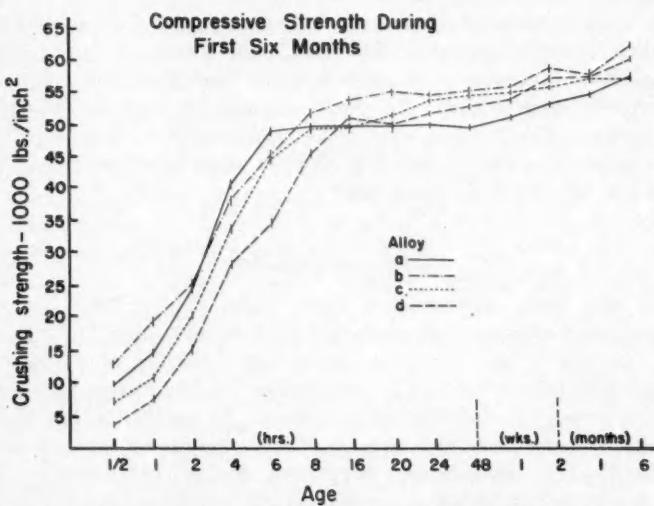


Fig. 1. Compressive strength of four alloys plotted against time. Note low strength during first few hours. Restoration is most susceptible to fracture at this time. (From Phillips, R. W.: J. D. Res., 28:348, 1949.)

preparation and proper manipulation, accidental stress placed on the restoration immediately after its insertion can cause fracture.

Flow

The strength of the amalgam alloy is closely associated with its flow. Flow is the measure of the ability of a material to retain its shape under constant load. Weak restorations are not only subject to fracture during mastication, but are also more likely to change in shape under normal biting stress. Although the laboratory flow test is a static one, it is generally felt that restorations which have a high flow value are more likely to result in failures such as flattened contact points, overhanging margins, and in severe cases a slight protrusion from the

cavity preparation. Again it must be remembered that the flow of any accepted alloy can be varied within wide limits by altering various factors in the manipulative procedure. For example, undertrituration may raise the flow value to as high as 8 per cent, twice the maximum value permitted by the specification. Inadequate condensation pressure, leaving excess mercury in the restoration, likewise increases flow. Thus, any portion of the technic which tends to reduce the strength will also increase the flow and will make the restoration more susceptible to change in shape during clinical service.

It cannot be overemphasized that an appreciation of the importance of these three fundamental properties to the success of the amalgam restoration is necessary if sound restorative dentistry is to be attained. Failure to control dimensional change and to maintain adequate strength can only result in clinical failure. Probably in no other dental material are the clinical manifestations of slightly inferior properties so vividly evident in daily practice.

CAVITY PREPARATION

As mentioned, improper cavity preparation, contributing to actual recurrence of caries and/or fracture, is the greatest single factor causing amalgam failure. Frequent among the violations of the fundamental principles of amalgam preparation are (1) failure to extend cavity margins to relatively immune areas, (2) insufficient provisions for bulk of material, (3) improper preparation of the cavosurface margin, and (4) inadequate retentive form. Failure to adhere to the fundamentals of good cavity preparation will invite subsequent clinical deterioration regardless of how meticulously the amalgam is handled during its manipulation.

SELECTION OF THE ALLOY

Most popular alloys have approximately the same chemical composition with the main difference being in the size and shape of the grains. In recent years there has been a definite trend to use of alloys having smaller particle sizes and this change has been beneficial. Since the bulk of the finished restoration is composed of particles of the original alloy surrounded by mercury and mercury-tin and mercury-silver phases, the original grain size does alter the character of the finished carved and polished surface. It would seem logical that the smoother surface of the small-grain alloy would be less susceptible to tarnish and corrosion and might be better adapted to the cavity walls. It has

also been shown that there is a definite relationship between strength and grain size—the smaller the grain, the higher is the one hour and 24 hour strength.⁴ Although some operators will prefer a certain brand of alloy because of its color, setting time, etc., generally a smaller grained alloy, or one whose filings readily break up into a small particle size, is preferred.

PROPORTIONING THE MERCURY AND ALLOY

There are many factors involved in the manufacture and in the manipulation of amalgam which are beyond the control of the dentist, but one of the variables which is directly under his control is the proper proportioning of mercury and alloy. Excess mercury used in the original mix unfortunately results in a higher percentage of mercury in the final restoration. This fact is true regardless of the amount of pressure or the technic employed during condensation. The increase in mercury content results in a reduced compressive strength, particularly during the first few hours after insertion.

Probably no one factor has more profound influence on the physical properties of amalgam than the eventual residual mercury content of the restoration. Analyses of clinical amalgam restorations show a wide variation in residual mercury, in some cases ranging as high as 70 per cent. The mercury content is invariably greater at the critical marginal areas, usually by 2 or 3 per cent. Current information seems to indicate that there is no cause for alarm if the residual mercury content can be held to approximately 50 per cent.¹² However, above this level the danger of a serious loss in strength becomes increasingly great. The dramatic drop in strength when the residual mercury content exceeds 55 per cent can be seen in Figure 2. Unfortunately, restorations containing residual mercury above 55 per cent are commonly observed.

Knowing then that the residual mercury does alter the resistance to fracture, what factors do influence the amount of mercury left in the restoration? These factors are: (1) original mercury-alloy ratio, (2) amount of trituration and (3) condensation pressure and time. Since the success of the restoration is dependent upon the sum total of all the variables involved and because the proper ratio can be maintained so easily, every dentist should take the time to employ the correct mercury-alloy ratio. Once the mercury-alloy ratio is established, it should not be altered, i.e., additional mercury should never be added during or following the mixing process.

A recent technic advocated by Eames makes use of minimal mercury (46 to 50 per cent) in the original mix.⁵ The merit of this technic

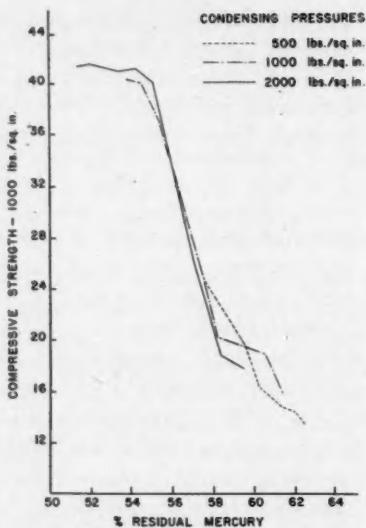


Fig. 2. Strength of amalgam as related to residual mercury content, showing marked reduction when mercury exceeds 55 per cent. (From Swartz, M. L., and Phillips, R. W., reference 12.)

would seem to be mainly in standardization since less premium is placed upon removal of mercury during condensation.

TRITURATION

The purpose of trituration is twofold: to reduce further the grain size of the alloy and to remove by abrasion the superficial coat of tarnish on each alloy particle. The clean metal is then readily attacked by the mercury. Of all the variables involved in the use of amalgam, none has a greater effect upon the physical properties than the length of trituration. Research has clearly indicated that undertrituration is to be avoided. An example of inadequate trituration can be seen in Figure 3. Regardless of the alloy, the strength of this type of mix is extremely low. Fracture and fraying of the margins will result and tarnish will be greater. If trituration is continued, strength will now be at a maximum, the amalgam will handle smoothly, the working time will be adequate and the carved surface will be more resistant to deterioration. Many variables, such as speed of trituration, size of mix and condition of mortar or capsule, will influence the time required to reach this consistency. Thus trituration should be standardized according to the conditions present in each office.

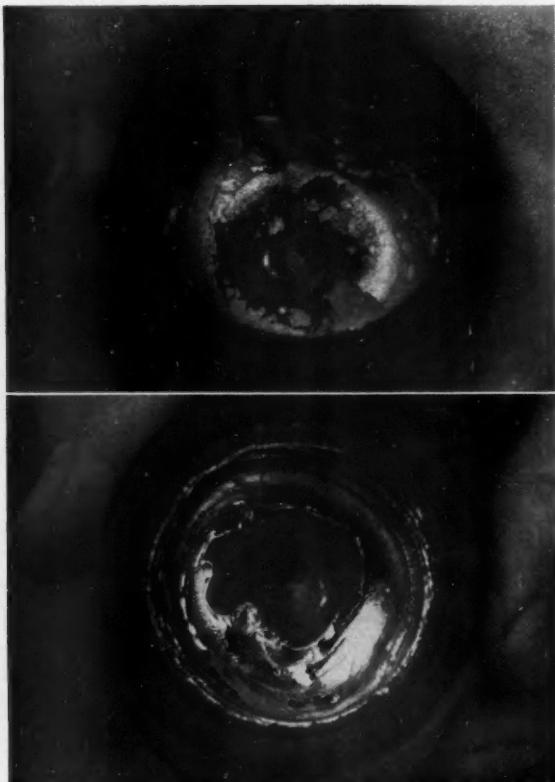


Fig. 3. Undertrituration (top) results in low physical properties and inferior restoration. Thorough trituration (bottom) is essential, regardless of mixing device. (From Phillips, R. W., reference 9.)

It is true that the longer the mixing time, the less will be the expansion. However, this reduced expansion or possible few microns contraction which will be produced is not clinically significant. The so-called "ditched filling" (Fig. 4) is often attributed to contraction. There is adequate evidence that such phenomena are not associated with this type of dimensional change.^{7,11} This type of failure is more probably due (1) to leaving a thin feather edge of amalgam after carving, which subsequently fractures (Fig. 5), (2) to the presence of unsupported enamel, (3) to inadequate condensation leaving this area mercury-rich, or (4) to actual expansion. The real danger in trituration lies with the many inferior properties that result from underamalgamation.

Mulling is not injurious to the amalgam but it should be done in a rubber dam to prevent any possible moisture contamination. Mechanical amalgamation does not necessarily result in a clinically better filling than a *properly* handled hand mix, but certainly it is advantageous if the mixing procedure has not been standardized. It is particularly



Fig. 4. "Ditched" restoration, an example shown here, cannot be attributed to contraction of the alloy. (From Phillips, R. W., reference 9.)



Fig. 5. One of the common causes for marginal failure, diagrammatically shown. Apparent contraction is in reality due to improper finishing of the restoration, i.e., leaving a thin ledge of amalgam which subsequently fractures. (Courtesy George M. Hollenback.)

beneficial in the case of the dental assistant who has not been properly trained or does not appreciate the importance of thorough trituration. Herein lies the real advantage of these devices. When mechanical amalgamators are employed, the capsule should be thoroughly cleaned after each mix. Particles of hardened amalgam left in the capsule will contaminate future mixes. With the new pellets, additional time must be allotted to break them up thoroughly.

MOISTURE CONTAMINATION

It has been demonstrated that contamination of amalgam with moisture results in a large delayed expansion. The zinc, which is present in all but a very few alloys, reacts with water and liberates hydrogen gas. This gas produces internal pressures within the restoration and causes protrusion from the cavity preparation (Fig. 6), possible pain to the patient, occasional blisters on the surface, and a marked reduction in strength. The excessive dimensional change has been shown to account for approximately 16 per cent of all defective amalgam



Fig. 6. Amalgam failure due to severe expansion, caused by moisture contamination. (Courtesy Harry J. Healey.)

restorations. This high frequency of failure emphasizes the care that must be exercised in the handling of amalgam to prevent contamination, which may occur from mulling in a perspiring palm, condensation into a wet cavity, or the incorporation of saliva during condensation. As pointed out previously, if mulling is desired it should be done in a rubber dam to minimize any chance of contamination, and the use of the rubber dam during cavity preparation is highly desirable. The rubber dam makes it possible to maintain a clear, dry field which permits the most meticulous operative procedures. In those cases in which saliva contamination cannot be avoided, a non-zinc alloy should be employed or proper packing procedure should be sacrificed for speed in inserting the filling. It is more important in these cases to condense the restoration rapidly enough to prevent any saliva contamination than to carry out the recommended proper, but slower, packing

technic. Generally these are posterior, cervical restorations which are not subjected to biting stress and in which maintenance of maximum strength by correct condensation is not essential.

In general the new non-zinc alloys now available must be considered experimental. When properly manufactured, they seem to have essentially the same physical properties as a zinc-containing alloy.⁹ Certainly whenever moisture contamination cannot be prevented, the zinc-free alloy should be used. However, there is no excuse for moisture contamination regardless of the composition of the alloy.

CONDENSATION

Various sizes and shapes of condensers are employed, and selection should be based upon the personal experience of each operator. Proper condensation is certainly one of the most important steps in the amalgam technic. One of the common causes of marginal failure is improper condensing of the material, and quite often recurrence of caries is due to a marginal breakdown. Poorly condensed amalgam presents cracks and crevices which promote tarnish and corrosion of the restoration in the mouth. Pitted fillings, which are so frequently seen, are often the result of improper and non-uniform condensation. Different techniques, in terms of the mercury content in each increment, are advocated for building the restoration. Little difference results in the physical properties whether the so-called "increasing dryness" technique is employed or whether dry portions are used throughout. Increments which are either too wet or too dry should not be utilized. To prevent any laminating effect in building the restoration, it should always be possible to work mercury to the surface during the packing procedure. Better adaptation is also secured by condensing with small rather than large increments.

The type of matrix retainer is a matter of personal preference. However, there is good evidence to indicate that failure to wedge and contour the band, regardless of retainer, will result in improper contour and gross cervical overhang which cannot be satisfactorily altered by trimming or flossing the proximal surface.²

Amalgam should not be allowed to stand too long before its condensation into the cavity preparation, particularly with the now-popular small-grained alloys which set rapidly. Amalgam which is allowed to harden for longer than three minutes will retain significantly greater amounts of mercury and the strength is drastically reduced (Fig. 7). Several mixes must be employed for large restorations.

If mechanical condensers are employed, drier portions can be used throughout since the action of these instruments does eliminate more

mercury from the restoration. Although impact or vibrating condensers do produce a slightly greater strength in the restoration than hand methods, the increase is not clinically significant. Certainly mechanical condensing does provide maximum packing pressure throughout the day regardless of how tired the operator may become. Its use, however, is optional.

The amalgam can be carved within two minutes after packing, but the margins must not be burnished at this time. Burnishing draws

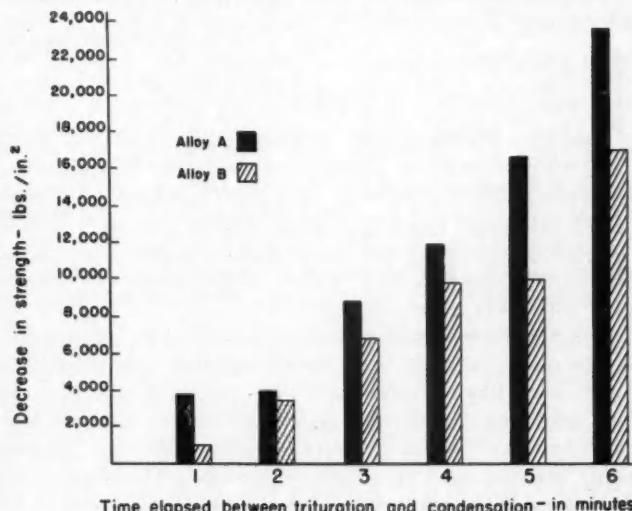


Fig. 7. As time between trituration and condensation increases, strength decreases. Amalgam older than three minutes should not be employed. (From Phillips, R. W., reference 9.)

excess mercury to that particular area, weakening it and making it more susceptible to tarnish and corrosion.

POLISHING

Amalgam restorations should be polished.⁸ Proper polish of the restoration will not only improve it esthetically but will aid in better adaptation of the margins and minimize subsequent clinical tarnish. Tarnish or corrosion of metallic restorations can usually be attributed to the presence of sulfur, and its incidence is influenced by mouth hygiene, by saliva pH and composition and, in particular, by the surface character of the restoration. A smooth and highly polished surface tends to prevent accumulation of debris and thus inhibits corrosion.

Polishing should not be attempted for at least 24 hours, and preferably not for several days. There should be no overhangs, and contacts with adjacent teeth should be rounded, not flat. The use of bevel-type plug finishing burs is advantageous in preparing the occlusal surface for polishing. Final polish is accomplished with amalgam brushes designed to remove the scratches from the grooves and sulci. Whiting and tin oxide applied with intermittent pressure produce the final high luster. It must be remembered that to polish the restoration properly there should be no excessive heat, as heat tends to draw mercury to the surface.

SUMMARY

Amalgam still remains the most commonly used restorative material. This fact, with the many desirable properties which it possesses, contributed to the continual research activity in this area. An appreciation of its basic properties and the effect of manipulative variables upon these properties is imperative to assure clinical success.

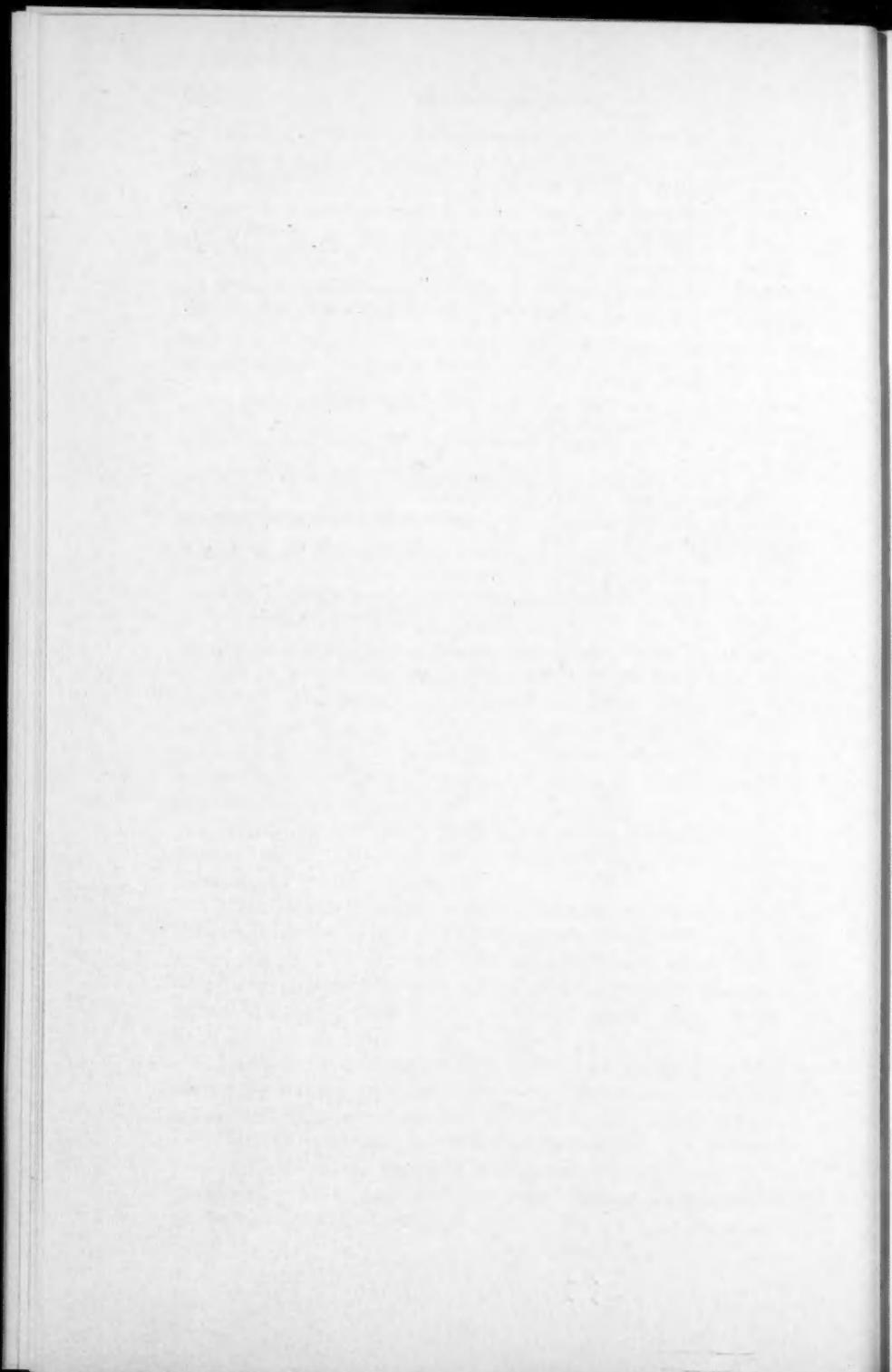
1. Use of small grained alloys permits better handling characteristics, a smoother surface and a stronger alloy.
2. There is now information on the exact relationship of residual mercury to compressive strength. Loss in strength is dramatic at the high levels often found in the clinical restoration, particularly at the marginal area. The chance of incorporating excess mercury can be minimized by using the manufacturer's mercury-alloy ratio, triturating thoroughly, condensing with adequate pressure and not using amalgam that has partially hardened.
3. Laboratory and clinical evidence indicates that undertrituration of amalgam is dangerous. Thorough trituration, either by hand or mechanically, must be employed.
4. Moisture contamination still remains a common cause of failure. Contamination by saliva or in mulling produces severe expansion and sharp reduction in strength. The non-zinc alloys seem to possess properties comparable to those of zinc-containing alloys. Whether they behave differently with respect to clinical tarnish is yet to be determined.
5. The resistance of any amalgam restoration to biting stress is low during the first few hours after insertion. The patient must be warned against accidental or intentional biting forces during that time.
6. Clinical tarnish can be minimized by polishing the restoration.

As with all dental materials, amalgam is extremely susceptible to many manipulative variables. Its clinical success is dependent upon meticulous attention to detail.

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Zinc Phosphate and Silicate Cements

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The zinc phosphate cements have been used in dentistry for three-quarters of a century, the silicate cements for over half a century. These cements are unique dental therapeutic agents and have no extensive commercial use. In common with most ceramic materials, the cements are brittle. Unfortunately their twin defects of relatively high solubility in the mouth environment and their noxious effect on the pulp have not been significantly reduced by research. Nor has a resin cement or a direct filling resin been made that has superior qualities in comparison with the zinc phosphate cements and the silicate cements, respectively. This means that with the present-day materials, the best one can do is to use a technic that will give the optimum values for the physical and chemical properties of these cements; optimum values, that is, for those properties which have a dental significance. A description of such technics and the reasons for them are the primary purposes of this report.

ZINC PHOSPHATE CEMENTS

Composition of Powder.⁵ The powders of modern zinc phosphate cements consist primarily of calcined zinc oxide and magnesium oxide in the approximate ratio of 9 to 1. Sometimes copper, silver or mercury salts are added to enhance antiseptic properties.

Composition of Liquid.⁶ The liquids of zinc phosphate cements are phosphoric acid solutions partially neutralized by the addition of aluminum and in some instances by the addition of both aluminum and zinc salts. The water content of the liquids is within the range of 33 ± 5 per cent.

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Composition of the Set Cement. The compounds formed as a result of the reaction between the powder and the liquid are phosphates of zinc, magnesium and aluminum. These compounds form only part of the set cement. The rest is the unreacted core of the larger powder particles. Thus, the set cement consists of powder particles cemented together with the phosphates. The proportion of the powder particles and the phosphate matrix varies with the amount of powder incorporated into a given amount of liquid. The set cement with the minimum amount of the phosphates gives the best values for the physical properties.

Certified Cements.¹ The zinc phosphate cements on the List of Certified Dental Materials (Table 1) have been certified to the Ameri-

TABLE 1. *Certified Dental Zinc Phosphate Cements (A.D.A. Specification No. 8, First Revision)*

CEMENT	MANUFACTURER OR DISTRIBUTOR
Ames Z-M	The W. V-B. Ames Co.
Bosworth's Zinc	Harry J. Bosworth Co.
Caulk Crown and Bridge;	The L. D. Caulk Co.
*Petroid Improved; Tenacin	
Certicem	Lee Smith Co.
Fleck's Extraordinary	Mizzy, Inc.
Lang Crown Bridge and Inlay	Lang Dental Mfg. Co.
S-C	Stratford-Cookson Co.
Smith's	Lee Smith Co.
S.S. White Silver Improved;	The S.S. White Dental Mfg. Co.
Zinc; Zinc Improved	

* Petroid Improved has been withdrawn from the market (J.A.D.A., 56:102, 1958).

can Dental Association by their respective manufacturers as complying with the requirements of American Dental Association Specification No. 8 for Dental Zinc Phosphate Cement.⁵ These cements were check tested by the research associates of the American Dental Association stationed at the National Bureau of Standards and were found to comply with the Association's standards (Table 2).

Significant Properties. The detail requirements of the American Dental Association Specification No. 8 for Dental Zinc Phosphate Cement and the range of values of the zinc phosphate cements on the List of Certified Dental Materials of the American Dental Association (Table 1) are given in Table 2. The effect of the comparatively small differences in values of the various properties has not been demonstrated clinically.

Technic of Mixing

The design of any mixing technic should center around the incorporation of the maximum amount of powder in a given quantity of liquid to produce the desired consistency. To do this, the hygroscopic liquid should be placed on the mixing slab just prior to beginning the mix. The slab should be chilled to 60° to 70° F. if possible to retard the reaction between the powder and liquid. The increments of powder should be small. At least one-half of the top surface of the 3 by 6 inch

TABLE 2. *Detail Requirements of A.D.A. Specification No. 8 for Dental Zinc Phosphate Cement, and Range of Values for Zinc Phosphate Cements on the List of Certified Dental Materials*

Detail requirements of A.D.A.	STANDARD	TIME OF SETTING AT 37° C. (99° F.)	COMPRES- SIVE STRENGTH	FILM THICK- NESS	SOLU- BILITY AND DISINTE- GRATION		ARSENIC CONTENT
	CONSIST- ENCY OF MIX				Minimum 7 days kg./cm. ²	Maximum microns	
Specification No. 8 for Dental Zinc Phosphate Cement	To produce disk	4	10	840 (lb./in. ²) (12,000)	40	0.30	0.0002 (1 part in 500,000)
	30 ± 1 mm. in diameter						
Range of values for Zinc Phosphate Cements on List of Certified Dental Materials	Grams of powder in 0.5 ml. of liquid	Minutes 7 ± 1	lb./in. ² 16,800 ± 4,000	Microns 30 ± 10	Percent- age 0.1 ± 0.1	Percent- age <0.0002	
	1.3 ± 0.3						

slab should be used during the mixing. The time of mixing should be approximately 1½ minutes. These procedures all tend to dissipate the heat of reaction and to incorporate the maximum amount of powder.

SILICATE CEMENTS

Composition of Powder.⁴ The powders of the silicate cements are powdered complex glasses consisting essentially of aluminosilicates containing magnesium, fluorine, calcium, sodium and phosphorus. The powders are quite stable.

Composition of Liquid.⁴ The liquids for silicate cement, like those for zinc phosphate cement, are aqueous solutions of phosphoric acid partially neutralized by the addition of aluminum or zinc salts or both. The liquids have a pH of approximately 2. Their water content runs about 40 ± 5 per cent. There is no such thing as a "neutralized" silicate cement liquid. Liquids exposed to air gain or lose water depending upon the relative humidity of the air.

Composition of the Set Cement.⁷ During the mixing the surfaces of the powder particles are attacked by the liquid, and a gel surface forms over each particle. The gel unites throughout the mass and binds the powder particles together. Thus, the set mass of cement consists of from 60 to 70 per cent of the undissolved powder surrounded by the set gel (Fig. 1).

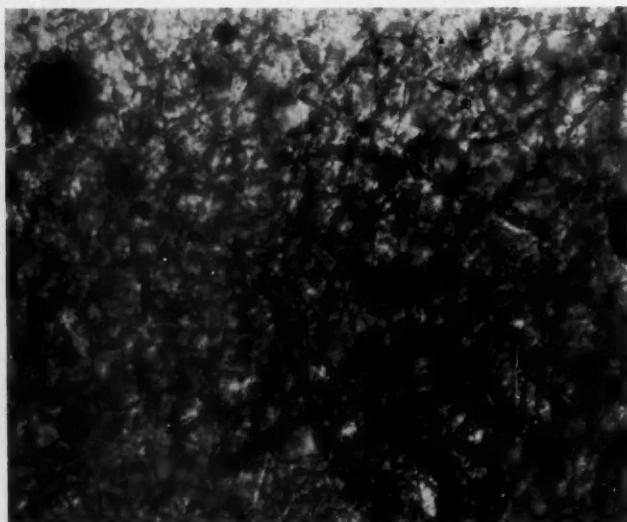


Fig. 1. Photomicrograph of the surface of a set silicate cement. Only the surface of the glass-like powder particles has been attacked by the cement liquid. Thus, the outline of the powder particles shows clearly in many places in the photograph. The material binding the powder particles together is the gel-like matrix formed when the liquid reacted with the surface of the powder particles. The round areas are air bubbles which are always incorporated during the mixing.

Certified Silicate Cements.¹ The silicate cements on the List of Certified Dental Materials¹ (Table 3) have been certified to the American Dental Association by their respective manufacturers as complying with the requirements of American Dental Association Specification No. 9 for Dental Silicate Cement.⁵ These cements were check tested by the research associates of the American Dental Association stationed at the National Bureau of Standards and were found to comply with the Association's standards (Table 4).

Significant Properties. The detail requirements of the American Dental Association Specification No. 9 for Dental Silicate Cement and the range of values of the silicate cements on the List of Certified Dental Materials of the American Dental Association (Table 3) are

given in Table 4. The clinical significance of these differences in values for the various properties is yet to be established.

Technic of Mixing

Previously, it was pointed out that the set cement consists of the unattacked portion of each powder particle bound together by the gel-like matrix which was formed when the liquid reacted with the powder (Fig. 1). This matrix is the soluble constituent of the cement. It causes the shrinkage, it stains and it is weak. In fact, most of the undesirable behavior of the silicate cements may be attributed to the

TABLE 3. *Certified Dental Silicate Cements (A.D.A. Specification No. 9, First Revision)*

CEMENT	MANUFACTURER OR DISTRIBUTOR
Ames Plastic Porcelain	The W. V-B. Ames Co.
Astralit	Premier Dental Products Co.
Baker Plastic Porcelain	Baker and Co., Inc.
DeTrey's Synthetic Porcelain; Syntrex	The L. D. Caulk Co.
Durodent Enamel	Oskar Schaefer
Smith's Certified Enamel Improved	Lee Smith Co.
S.S. White Filling Porcelain Improved	The S.S. White Dental Mfg. Co.

matrix. Therefore, any sound mixing technic is based upon holding the amount of matrix down to a minimum. The mixing slab should be chilled to just above its dewpoint. This retards the reaction between the powder and liquid during mixing. Thus, a larger amount of powder can be incorporated into a given quantity of liquid when the mix is made on a chilled slab than when the mixing is conducted on a warm slab. If one makes the mix in a small rubber sack under cool water, then the maximum amount of powder can be incorporated regardless of atmospheric conditions.² A motion picture film showing such a technic is available on loan from the National Bureau of Standards or the American Dental Association.

The mix should be made as rapidly as possible to minimize the formation of excess matrix. No longer than 30 seconds should be used. As small an area of the mixing slab should be used as is practicable so as to minimize the exposure of the hygroscopic unset cement to the atmosphere. The mix should attain a heavy putty-like consistency. In short, one should make a thick mix on a cool slab as fast as possible. This will minimize the amount of matrix formed.

TABLE 4. *Detail Requirements of A.D.A. Specification No. 9 for Dental Silicate Cement, and Range of Values for Silicate Cements on the List of Certified Dental Materials*

STANDARD CONSISTENCY OF MIX	TIME OF SETTING		COMPRESSIVE STRENGTH		OPACITY		SOLUBILITY AND DISINTE- GRATION		
	37° C. (99° F.)	AT	Minimum	Maximum	Minimum	Maximum	Maximum	Maximum	ARSENIC CONTENT
Detail requirements of A.D.A. Specification No. 9 for Dental Sili- cate Cement	To produce disk 25 ± 1 mm. in diameter	3 minutes	8 minutes	24 hours kg./cm. ² 1,620 (lb./in. ²) (23,000)	0.35 C _{0.70}	0.55	24 hours percent- age by weight 1.4	Maximum percent- age by weight 0.0002 (1 part in 500,000)	
Range of values for Sili- cate Cements on List of Certified Dental Materials	Grams of powder in 0.4 ml. of liquid	Minutes 5 ± 1	lb./in. ² 25,200 ± 2,000	C _{0.70} all within 0.35-0.55	1.0 ± 0.3	<0.0002	Percentage 1.0 ± 0.3	Percentage <0.0002	

Technic of Insertion

As soon as the mix is completed, it should be transferred to the cavity. The matrix strip should then be drawn tight and held in place until the cement has hardened. One should not guess at the time of hardening, but should use a test piece made from the excess cement remaining on the slab. Every attempt should be made to judge the correct amount of cement to be packed into the cavity so that a minimum amount of finishing will be required.

After withdrawal of the matrix strip, the cement should be covered with a grease such as petrolatum, U.S.P. or a silicone stopcock grease such as is used in scientific laboratories. Some prefer a low-melting paraffin wax as a coating, as it is a very effective water barrier.

TABLE 5. *Change of Compressive Strength of a Silicate Cement with Time*

AGE OF SPECIMENS	COMPRESSIVE STRENGTH, LB./IN. ²
15 minutes	10,000
1 hour	12,000
3 hours	15,000
1 day	16,000
1 week	19,500
6 months	22,500
14 months	24,000

Technic of Polishing

Delay any polishing or dressing down for at least 24 hours because the silicate cements become much stronger with time as shown in Table 5. Under no circumstances should the restoration be made flush with the enamel margins just after removal of the strip. To do so breaks off the weak margins of the restoration and makes a V-shaped crevice at the enamel-restoration margin.

None of the abrasives in the dental office will produce as smooth a surface as that left by the retaining strip. Only the finest grit of cuttlefish disks should be used slowly, and they should be covered with grease to minimize frictional heat and to protect the newly uncovered surface from air or from saliva.

Care of Silicate Cement Restorations

If a patient is a mouth breather, he should be instructed to coat his silicate cement restorations with petrolatum every night before retiring. Otherwise, the silicate cement restorations will last only a few

months because silicate cement shrinks badly when exposed to air. Silicate cement restorations should also be protected similarly when isolated by the rubber dam.

Theory and Practice

Demonstrations in the scientific laboratory can be made the basis for predicting the effectiveness of silicate cement restorations, as

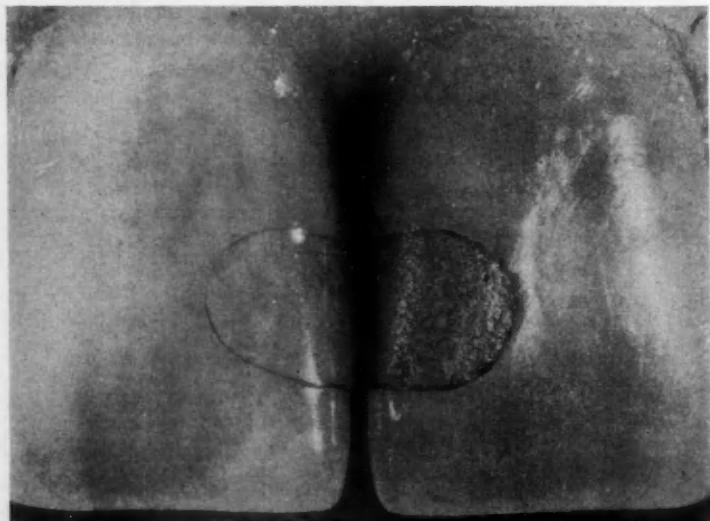


Fig. 2. The same brand of silicate cement was used in making these two restorations. The restoration at the reader's left was made from a mix spatulated on a slab at 60° F. for 30 seconds. Petrolatum was placed on the restoration immediately after removal of the matrix strip. Finishing was delayed for one week. The restoration on the right was made from a mix spatulated for two minutes on a slab at 98° F. Immediately after removal of matrix strip, the restoration was dressed down flush with the enamel. The photograph was taken a few weeks after the restorations were placed.

shown in Figure 2.³ These two restorations were made with the same brand of certified silicate cement. The good filling, at left in the photograph, was made from a mix spatulated 30 seconds on a slab at 60° F. Petrolatum was placed on this filling just after the matrix strip was removed. Finishing was deferred for one week. The poor restoration, at right in the photograph, was made from a mix spatulated for two minutes on a slab at 98° F. Saliva came in contact with the restoration after removal of the matrix strip. Immediately thereafter, the restora-

tion was dressed down flush with the enamel. The photograph was taken a few weeks after the fillings were inserted.

**EFFECT OF ZINC PHOSPHATE AND SILICATE CEMENTS
ON THE PULP; PROTECTION OF THE PULP**

Any cement based upon a phosphoric acid liquid injures the pulp. The injury caused by zinc phosphate cements is less severe, more transient and more frequently resolved than pulpal injuries caused by the silicate cements. Calcium hydroxide alone or bonded with other agents is very effective in preventing damage to the pulp by phosphoric acid cements. Cavity varnishes without alkaline components appear to give partial protection. Usually the thicker the dentin between the cavity and the pulp the less the amount of pulp damage.

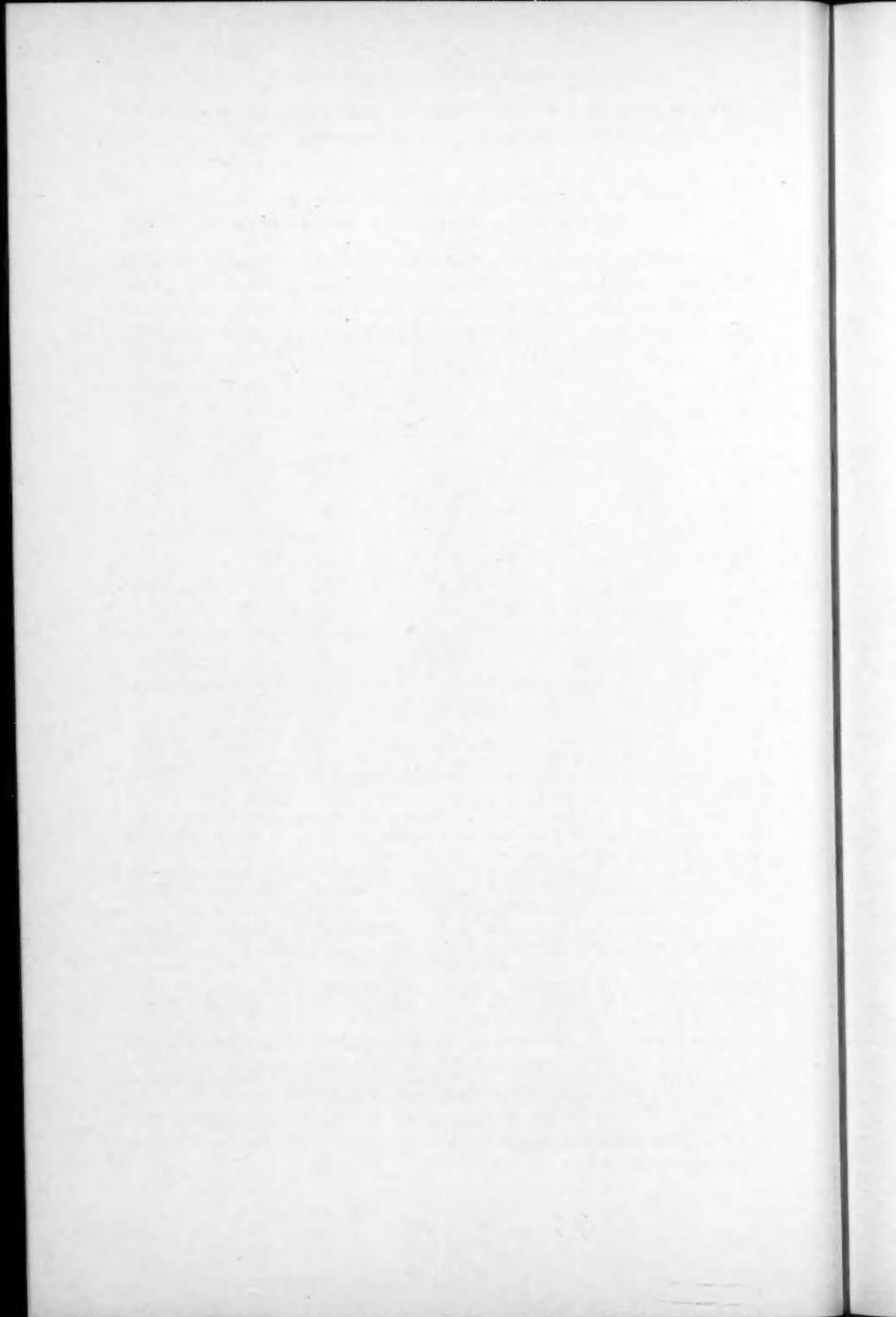
RÉSUMÉ

1. It is not only necessary to select a satisfactory cement but it is just as important, if not more so, to use the cement properly.
2. A cement is used properly when the technic of handling is designed to enhance its desirable physical and chemical properties.
3. The values for the properties are significantly influenced by the technic of using.
4. Laboratory and clinical testing can be correlated as demonstrated in Figure 2.

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Correlation of Physical Properties and Clinical Aspects of Gold Foil as a Restorative Material

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Restorative materials used in operative dentistry are substitutes for diseased or missing tooth structure. These materials with which we restore portions of the anatomy of the natural tooth should be evaluated in comparison with tooth structure itself. Laboratory evidence, such as tables of thermal coefficient of expansion, Brinell hardness, etc., give us scientific data, and with this empirical information we have certain tools for comparison and measurement. This information, and these tools, should be used to indicate to the clinical dentist how well, or how poorly, he might expect a certain material to substitute for missing natural tooth structure.

Gold foil has often been judged by many as a teaching aid, an exercise or a test of technical dexterity, but we shall attempt to disregard this approach and evaluate gold foil from the standpoint of service to the patient. In selecting any material for a possible service, we must carefully examine the location, classification and type of area to be restored, and we must also consider the occlusal or biting stress because we cannot expect weak and fragile materials to serve under severe and repeated stresses.

Years ago gold foil was often used where it was contraindicated or where another material could be used to greater advantage. In the past we have seen foil used in occlusal class I cavities where silver amalgam would have served as well or better, and we have seen foils placed in large class II cavities where inlays could do better service. On the other hand, today we see less adequate and less serviceable materials applied where foil would serve the patient much better. In view of this we shall confine our discussion of gold foil to the areas where its use is principally indicated—the class III, IV and V cavities. In the gingival cavities it should be judged generally against the amalgams and inlays in the posterior part of the mouth and the silicates and acrylic resins in the anterior. In the interproximal class III cavities it is compared with the silicate cements, resins and lingual drawn

inlays, and in the class IV cavities its choice is against the silicate, resin or inlay.

ESTHETICS: FORM AND COLOR

Many sizes, shapes and colors of gold foil restorations are observed. Some of them are pleasant to the vision and others are not. It is not fair for critics of foil restorations to judge all foils by those that are not well planned and are constructed without proper consideration for esthetic values.

Certainly the color of gold is not ideal, but gold has long been perhaps the most important and generally accepted material in restorative dentistry. The dentist, and the dental patient for whom extensive restorative treatment is planned, begin with an acceptance of gold as a material and as a color—we are all used to it. Until we find a material that will serve as does gold in the preservation of teeth and still has a more desirable color, we must accept gold for what it is and what it will do.

Form

First we might consider form or anatomy in our discussion of esthetics. Certainly Rodin or Michelangelo could have done better when they created their famous masterpieces in sculpture if they had used a material that perfectly reproduced the color and texture of skin. Most of the world's great art is in marble because that material yielded itself to the reproduction of form and, more importantly, because it maintained that form in permanency. It was certainly not used because it was easy to manipulate or because its color duplicated nature. Basically it was used because with it the artist was able to duplicate with extreme intimacy the anatomy of the human body in lasting form. This same characteristic should be considered when we reproduce a portion of a missing tooth in reparative dentistry. More important even than color is the anatomy and detail of the restoration. It is not right that we remove the infected and missing tooth structure and pay no attention to the esthetics of the cavity outline and the carving of detail with its important consideration of lights and shadows, convexities and concavities, ridges and grooves. If the missing tooth structure has been replaced with a restoration of good form it will be less conspicuous to the eye. If it has good tooth anatomy and matches in form the mate on the other side of the median line, from the standpoint of form, it will be esthetically pleasing. If the form is not carefully reproduced and there is a noticeable deviation in anatomic detail from its mate, the restoration strikes the eye of the observer with an unesthetic impact.

Gold foil permits the reproduction of form very well because of its desirable yield to carving. A gingival cavity can be restored to duplicate exactly the original tooth, and so also can an interproximal cavity when a portion of the labial wall is missing; in a class IV restoration the angle of the anterior tooth can be made to maintain the detail of its original form.

Color

Gold foil comes in many colors. We have all seen the dark brown or almost black appearing foil in the anterior part of a patient's mouth, and we have seen foil with a red effect, but it is more pleasant to see light yellow foil, which blends very well with the yellow of much enamel. Basically this approach toward lightness is accomplished by better condensation techniques. Foil that is poorly condensed is darker because of its lack of proper light reflection. In the softer, more pitted foils there are many air pockets which soon become filled with moisture and organic material, and in these there is a tendency for greater tarnish and oxidation. Platinum-gold foil, which has a lighter color, is not generally used or often indicated; its usual application is on the incisal angles where greater hardness is desired.

The way the surface of the gold foil is condensed and finished is of the utmost importance in the color and esthetic effect of the material. It should be condensed with careful stepping and with relatively smooth condensing points to produce a perfectly smooth surface without pits. However, it is a mistake to polish too highly the surface of the foil that meets the eye. When a gold knife is used on the proximal surface, a mirror-like effect is often produced. This is desirable under gingival margins and on the lingual and interproximal surfaces that do not meet the eye; sometimes these areas are finished by the use of hand burnishing instruments in order to produce the mirror-like effect, which also results in hardness and a surface that is easily kept clean. But on the surface that meets the eye it is not desirable because of the problems of light reflection. We do not want this surface to act as a mirror and thereby call attention to itself with a flash. The surface of enamel is made up of many ridges, depressions and unevenesses that break and diffuse the light rays instead of reflecting them as does a mirror surface. With this thought in mind we should finish the foil on these surfaces with a finely scratched sand finish. This surface has many tiny hills and valleys that break up the light reflections in many different angles rather than bouncing back directly to the viewer's eye. This desirable effect is not accomplished with the exceedingly fine polishing powders (e.g., rouge) that are often used in a relatively dry state to produce "shine,"

but rather we leave the finished surface scratched by the reasonably fine cuttle strip disk. Often we are able to produce the right type of color and surface with the use of a wet medium pumice applied with the rubber cup or small brush, and if this is washed off in a wet state we have a light yellow surface that is quite esthetic and does not call attention to itself. Actually the contour and color of some properly finished restorations in gingival cavities blend so well into the gingival tissues and line that they appear to be an extension of the gingival tissues.

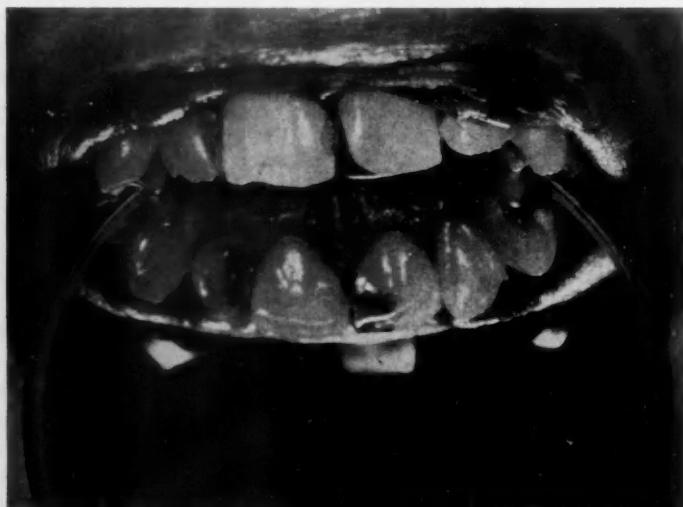


Fig. 1. A class IV gold foil restoration employing the author's design, in which graceful curves are emphasized.

Although esthetics is important in choosing a restorative material, this factor should not supersede considerations of health or function. With this in mind we should be aware of the difference between treating incipient caries in a young patient and replacing a failed restoration in an older patient. Foil lends itself to excellent esthetics in the incipient class III cavity in younger patients because it is usually not visible when properly placed. On the other hand, the material is blamed for undesirable esthetics because it is often called upon to repair the damage resulting where one or more acrylic or silicate restorations have failed.

Cavity outline and design are also important considerations in esthetics. Poor planning of outline should not condemn the material that would be less conspicuous with good outline. This is evident in

CLASS IV OUTLINE

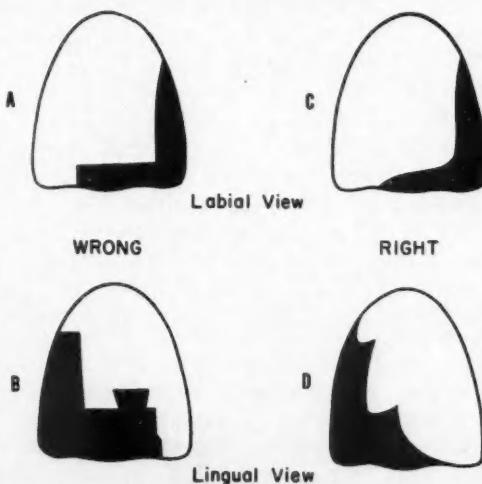


Fig. 2. A, B, Labial and lingual views of conventional form in class IV gold foil restorations. C, D, Labial and lingual views of the author's design for a class IV restoration.

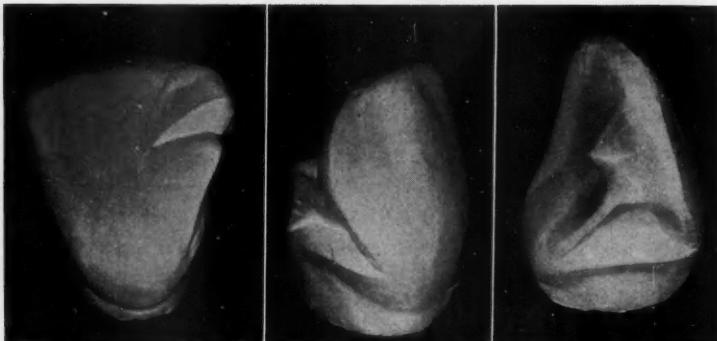


Fig. 3. Harmonious outline suggested by the author for his class IV gold foil restoration.

the advantages of the Woodbury, Ferrier and True outlines over older conventional outlines. The esthetic effect of the author's class IV design (Fig. 1) is also made more harmonious and pleasing to the eye than the older conventional form. Sharp corners and severe straight lines (Fig. 2A and B) are not nearly as harmonious as are the rounded lines and graceful curves (Fig. 2C and D, Fig. 3) that blend with the natural anatomy of the tooth form.

THE CAVITY SEAL

The cavity seal is of utmost importance. Recent investigations^{2,4,9} with radioactive isotopes have proven that no material completely fills and seals the cavity microscopically, and it has been demonstrated that percolation takes place at the margins of all types of restorations owing to the effect of hot and cold materials contacting the tooth and restoration. These considerations of cavity seal are of importance clinically only when the restoration permits gross invasion of bacteria and fluids at the margins. Bacterial invasion at the margins results in complete failure of the restoration to accomplish its primary purpose, that of keeping the elements of infection from the pulp tissue. When the enamel of a tooth is broken or has been attacked by caries, we must restore and repair it with a material that will seal off the dentinal



Fig. 4. An adequate bevel is essential to provide an effective seal at the cavity margins. Gold foil, because of its mechanical properties, permits such a bevel.

tubules as nearly as possible as did the original enamel. This means simply that we must achieve a bacterial seal of the cavity margins.

In planning a seal of the cavity margins with the restorative material, an adequate bevel is essential (Fig. 4). Materials that curl at the bevel as do the acrylics, or that fracture in thin areas as do silicate and amalgam, do not permit the broad bevel that can be achieved with gold. This susceptibility of gold to beveling is of great importance clinically and greater advantage should be taken of it by the operative dentist.

It is reasonable to assume, from clinical experience, that most of the vulnerable marginal areas can be covered to good advantage by a generous bevel of foil, particularly to prevent postoperative sensitivity to hot, cold, sweets, etc. It is also possible to use inlays as well as foils on the class V cavity in the same way, but inlays on the class III cavity cannot accomplish the generous labial bevel that is possible with the foil. With the use of finishing strips to bevel before the application of foil we are able to wrap foil around the enamel margins

and effect a more adequate cavity seal. This shingling effect with foil is also of great value in protecting the lingual margins of the maxillary class III cavity in wear from the labial and incisal edges of the lower anterior teeth. A butt joint of enamel on the lingual aspect of the class III preparation will permit the enamel rods to fracture and fall out, leaving a void at the margins, but with foil we are able to cover this enamel margin and protect it in wear. This same shingling effect is of utmost importance in the protection of the incisal margins in class IV preparations. We must always avoid the butt joint here; fortunately, with well condensed and highly tempered foil we are able to protect this enamel. Experience proves that as the patient wears this area of the incisal edge of the upper anteriors with the incisal edge of the lowers he burnishes and further contours the foil labially. There are those who object to the use of foil in long thin bevels, suggesting that they will curl back, but clinical experience does not bear out this supposition. Foil will remain in its intended position and wear as does the tooth itself if the cavity margins are so planned that the incisal and masticatory stresses tend to burnish the foil against the enamel wall rather than away from it.

CONDENSING INSTRUMENTS

There are three methods being used generally in the condensing of the modern gold foil restoration. The first method employs the Hollenback pneumatic instrument, which is perhaps the most generally used and has been very popular during the last twenty years. The second method used by many experienced operators is the older method of condensation with hand condensers and the hand mallet used by the assistant; it often produces results that are second to none. The third and newest method utilizes the electric mallet that has been recently developed in Southern California; this technique offers considerable promise for achieving good results.

The results achieved by these three methods do not depend so much on the instrument as upon the operator and his experience with the particular method of condensation. It also seems that there are particular places and situations in which one of the three methods of condensation works better than the other two methods. Some operators use all three of the means of condensation, depending on the particular situation. Often it is found that the use of the hand instruments allows the operator to compress the foil in retention areas better and with greater ease, and he may then proceed with the pneumatic instrument or the electric mallet, with more rapid blows and with larger condenser instruments, and develop greater hardness. It seems that all

three of the instruments have their particular advantages and disadvantages. The younger operator just beginning to use foil would perhaps be better off to use the new electric or the pneumatic mallet, but he should know that the occasional use of the hand mallet would be very advantageous in particular situations. Certainly the type and rapidity of blows delivered by the electric mallet offers new horizons in speed and hardness.¹ The use of this instrument with the smoother faced points and a type of burnishing action should be investigated by the operator.

TYPES OF FOIL

Foil is generally used in three different forms. First are the popular cohesive pellets, which become cohesive after the application of heat that is used to drive off moisture and gases. Second, we hear increasingly more about the use of mat foil,¹ which is a crystalline preparation that becomes very cohesive when it is heated properly. It is more difficult to remove the air from it in condensation than from the regular pellet type of cohesive foil, because the mat foil is bulkier and more sticky. It does not seem to be as desirable for strength and surface finish as the regular cohesive material, and it is used generally to provide bulk in the deeper portions of the larger class V preparation where strength is of lesser importance, and it is usually used in conjunction with the regular cohesive foil which is depended upon for the important retentive areas and the margins and exposed finished surfaces. Each of these materials has its proper place, and the conditions of usage should be considered carefully before a selection is made.

The third, and oldest, form of foil is used by more experienced operators in the building of bulk in class II cavities. It is a non-cohesive cylinder that is folded from sheet form and is not heated. It remains softer in the cavity and is used in the interproximal and gingival areas where there is no occlusal stress on it. It can be made to fit intimately into cavity detail because, unlike cohesive foil, it continues to move and condense much beyond the surface as pressure and blows are applied. The non-cohesive cylinder is used in conjunction with cohesive foil which retains it and takes all occlusal wear and stress. The advantage of the non-cohesive cylinder is that it allows for a large area to be filled very quickly; it is a material of expediency, as is the mat foil. The places for the use of the non-cohesive cylinder are rather limited, and it might be disregarded by the average operator. He should confine himself to the use of cohesive pellets in the smaller cavities for greatest success and service.

DEPTH OF CONDENSATION

We should realize that, particularly with regular cohesive foil, we should not expect to condense the foil deeper than the immediate pellet on the surface. Too often operators imagine that they can condense a considerable mass of uncondensed foil by applying heavier blows. To achieve a well condensed foil with sufficient strength we must condense each pellet as it is added to the mass. The only foil that we condense is on the surface, and the effect of the blow does not penetrate into the deeper portions of the material. Often when foils bend, leak or become partially displaced it is because each pellet was not thoroughly condensed when it was placed in the cavity.

The size of the condenser point is also an important consideration. The larger the face of the condenser point, the greater must be the blow that is required to condense the pellet properly. Smaller points and pellets should be used when we desire greater strength of the mass, although reductions in both time and trauma can be effected by the use of larger points and pellets in the larger foils, especially when the building of volume of material is the prime consideration.

BURNISHING

It is interesting to note that the burnishing effect of occlusal and incisal wear tends to harden the well condensed foil. We have long understood that when we hand-work metal by burnishing movements we temper and harden it. Masticatory wear and the burnishing effect of hand instruments on foil harden it. The foil starts out very soft and uncondensed, but as we mallet it and work it we harden it, and it is surprising to what extent this hardening will take place if we burnish the foil toward the enamel margins with many rapid blows of the mallet. We have experienced this especially with the Hollenback pneumatic mallet, and more recently with the new electric mallet. It is often desirable to use a skidding movement toward the margins that produces intimate adaptation and increased hardness, especially when using condenser points that are rather smooth on the face. For many years we used serrated amalgam condensers because we believed that the roughness made by them helped the next piece of amalgam to cohere with the mass, but during the last several years we have gone toward smoother faced condensers because we have learned that roughness is not the factor that produces the cohesion. This is also true to some degrees in foil.

It must be remembered that there are four primary purposes in the condensation of a foil restoration: first, to contact intimately all the detail of the cavity with the material; second, to eliminate the air

space from the cavity and from the uncondensed foil pellets; third, to harden and temper the mass so that it will have sufficient strength to compare favorably with the original structure that it replaces; and fourth, to protect the frail cavity margins in the enamel.

LINE OF FORCE

The line of force used in condensing gold foil, though of great importance, is often neglected. It may be defined as the direction in which the condenser points and in which the force of the blow is directed. This line should generally be directed toward the surrounding walls of the cavity. It is our desire to fit the foil as tightly and intimately as possible to a particular wall, margin or bevel, and to do this we should direct the line of force as nearly as possible at right angles to it.⁵ To produce a tightly fitting restoration that will resist leakage at the margins and walls we must first build the foil against one wall, then hold the material very tightly against this wall as we change the line of force against the opposite wall. We cannot expect a successful seal of a lingual wall on a class III cavity if the line of force used to build up this lingual is directed gingivally, as it often is. In this example the position of the condensing instrument must be changed from the gingival direction to deliver the blow directly against, and at right angles to, the lingual wall we are attempting to seal.

GINGIVAL ACCEPTANCE

For many years the clinician has noted the desirable way in which the gingival tissues adapt themselves to foil that runs below their margin. No other material seems to have a greater degree of gingival compatibility. Zander¹⁰ and Waerhaug⁸ noted that there seemed to be a cellular attachment to foil that was sealed to the roots of teeth that were extracted and reinserted into the sockets. This indicates that the foil itself has no qualities that repel cellular growth and development, and we would expect this because of the negative chemical reaction of gold.³ Then, too, we know that a very well condensed foil can be finished almost perfectly smooth, and this characteristic has long been proven to be desirable for contact with living cells. Periodontists try to achieve a smooth polish on roots which is similar to the well finished foil. Perhaps the most important factor is that with a long bevel under the gingival margin we have no irritating crevice between the filling material and the cavity margin. Even with the best inlay there is a minor crevice that is filled with cement. This cement in itself is rough and chemically irritating, and, as it dissolves out to any de-

gree, it allows an open crevice that harbors bacteria and other materials.

With any material there tends to be a percolation factor at all margins, probably because of the differences in coefficient of expansion of the various materials and the tooth structure itself. The ratio of the linear coefficient of expansion of gold foil to that of tooth structure⁶ is only 1.3. This small difference may be compensated for to a great degree by making a long gingival bevel that will produce, in effect, a sliding-joint action (Fig. 5B) that permits few or no crevices which will harbor bacteria. This point may account for the very good

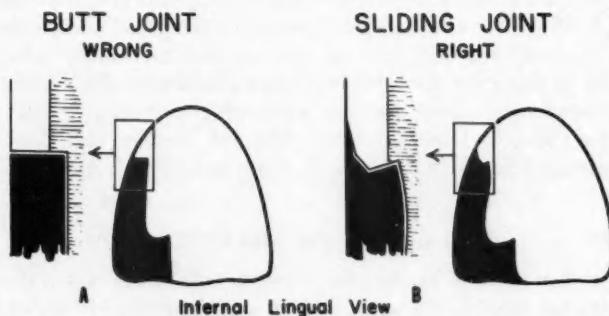


Fig. 5. A, Butt joint at gingival margin of class IV gold foil restoration allows formation of crevice that may harbor bacteria. B, Sliding joint prevents formation of crevice.

clinical results obtained by foil throughout the years. Perhaps we should try to finish more of our gingival margins so that the adjoining surfaces of the tooth structure and the restorative material are parallel to the long axis of the tooth rather than at right angles to it as in the gingival butt joint. We should consider the advantage of the sliding-joint margin produced by the gold crown rather than the right-angle margin suggested for the acrylic. This sliding joint might to some degree explain the clinical effectiveness of the gingival margins in the "slice" inlay preparation, or especially the old full shell crown. With these joints that were made parallel to the long axis of the tooth rather than at right angles to it, perhaps a more desirable condition existed than in the butt joint, which would be opened by the change in dimension of the restoration in response to thermal change.

ANATOMY AND THE IMPORTANCE OF CONTACT

Gold foil maintains its anatomy in the gingival class V cavity much better than the silicate restoration, and this desirable contour, as well

as the smooth surface, is important to the health of the gingival tissues.

One has only to study the worn contact areas of natural extracted teeth to be impressed with the great importance for hardness of the restorative material that is used to restore contact areas in class III and class IV cavities. These contact areas are designed by nature as smooth convexities, and their function seems to be the protection of the gingivae and interproximal alveolar crest from food impaction and trauma. The well formed and hard contact areas prevent excessive mesial drift of teeth, and these same characteristics of form and hardness can readily be achieved and maintained with properly handled foil. It is of great importance that the foil be tempered and condensed in the contact area with the greatest of care to develop adequate hardness in this area. Certainly we must guard carefully against pits and uncondensed areas for the sake of cleanliness. Poorly condensed areas in foil are not clean, and it is evident that these pits soon become filled with moisture, bacteria and organic material.

HARDNESS AND STRENGTH

The well made foil has greater strength than other materials used in certain cavities.⁷ There is certainly greater hardness in enamel than in any of the restorative materials we use, but when we repair or restore it we find it advantageous to use a material that is similar in hardness and wears rather evenly with the surrounding enamel. The very hard inlay gold often becomes too high as it wears unevenly in relationship with the enamel, and the pure gold casting may wear more rapidly than the surrounding tooth structure, but the tempered quality of the well condensed foil seems to be the nearest to the ideal that we have yet achieved. Many experiences show a beautiful evenness of wear when we build up the incisal edges of anterior teeth with foil. Foil's degree of hardness allows it to replace the softer dentin in cases of severe incisal or lingual abrasion, and it works equally well in the restoration of incisal angles in the MI or DI restoration. In these and in the interproximal restorations, the lingual surfaces that are restored wear evenly with the enamel.

RETENTION AND MATERIAL STRENGTH

In the cast inlay where pins are used for strength we often see small gauge iridioplatinum pins used for retention, and although such small bulk serves here because of the nature of the material, we must use more bulk for the retention of foil. Too often we see displaced foil

restorations that have depended on similar small caliber points made of gold foil. The lesser strength of foil demands greater bulk in the planned retentions. We should use bars of gold rather than pins or pot-holes—this is particularly true when there is great stress from the opposite arch applied to the restoration, as in class IV and, often, class III restorations. It is possible to place the foil and to finish it with inadequately planned retention areas, and although the immediate result seems good, the foil will often be loosened or displaced

STRENGTH IN RETENTION AREAS

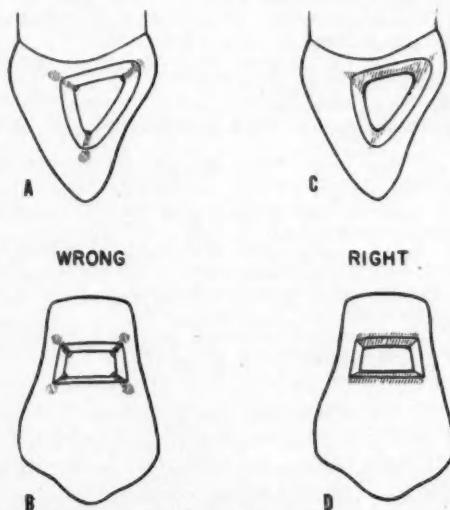


Fig. 6. The triangular (C) and bar-shaped (D) retentive areas are much more effective than the pin and pot-hole types (A and B).

under the long and repeated stress of function. It is less important how the restoration looks immediately following the operation than how it will serve throughout the years.

Bars built into undercuts (Fig. 6D) on the gingival and occlusal margins are more desirable than the older pot-holes that have only convenience value in starting the foil, but very little actual retentive value. The gingival retention of well developed triangles of gold (Fig. 6C) in class III and class IV cavities is necessary and more desirable than the simple bur-produced undercut. We should note that the hardness and strength of the material encourage us to build greater bulk in important areas in order to produce the required resistance to displacement.

CONCLUSIONS

The physical properties, cavity design and manipulations of the material for the gold foil restoration have been discussed. As judged by its physical properties and from the standpoint of service to the patient, gold foil is at present indispensable in preserving the natural teeth in a state of function and health.

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An Evaluation of Cavity Liners and Intermediate Base Materials

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The protection of the pulp and the elimination of postoperative discomfort to the patient have long been the goals of all dentists. As a result, cavity liners and intermediate base materials have been widely used. The purpose of this paper is to evaluate the efficacy of the more popular of these agents when they are employed beneath the various restorations in operative dentistry. Three criteria will be used in this evaluation: (1) the ability of the material to protect the pulp; (2) the ability of the material to eliminate postoperative discomfort; and (3) the effect of the material on the clinical success of the restoration.

It should be emphasized in the very beginning that no intermediate base can safely compensate for trauma to the pulp due to injudicious cutting of fresh dentinal tubules. The dentin and the pulp possess a physiologic intimacy which precludes the irritation of one without irritation of the other. With the increased popularity of the higher rotational speeds for cutting instruments, the use of coolants during cavity preparation is mandatory. The most efficient coolant is an air-water mixture spray; it should be used when cutting away the bulk of the tooth structure. Refinements in cavity preparation should preferably be accomplished with hand instruments but when they are achieved with rotary tools, air alone is a sufficient coolant.

SILICATE CEMENT

The toxic effect of silicate cement on the pulp is well established.^{8,17} At one time pulpal death was very common due to the placement of silicate fillings in young teeth. While postoperative discomfort is rare,

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the possibility of pulpal necrosis necessitates protection of the cut dentinal tubules in a cavity for silicate.

Zinc Cement

Zinc cement has been used with some clinical success as an intermediate base under silicate fillings, but this material is also an irritant to the pulp in all but very shallow cavities.⁴ Owing to the size of the young pulp and the necessity of cutting the cavity sufficiently deep to accommodate both the base and the silicate filling, the use of an oxyphosphate of zinc cement is hazardous to say the least.

Zinc Oxide and Eugenol

Other careful operators have used a zinc oxide and eugenol base for pulp protection beneath silicate, but again this requires the sacrifice of sound internal tooth structure or the loss of the necessary retentive features of the prepared cavity. At one time the author filled all young teeth to receive silicate with zinc oxide and eugenol and then exercised what Seltzer¹⁵ has called "a period of masterful inactivity." After approximately three weeks the pulp had had an opportunity to lay down a layer of irregular secondary dentin to protect itself. At the end of this period the treatment filling was removed and the silicate was inserted with a fair degree of safety. This of course required two visits, which added to the expense of the restoration to the patient.

Calcium Hydroxide

In 1949 Glass and Zander¹ reported true healing of exposed pulps when treated with calcium hydroxide, and a year later Zander, Glenn and Nelson¹⁶ demonstrated the ability of this chemical, when used as a cavity liner, to eliminate the pulpal damage caused by silicate. There are several proprietary preparations on the market, such as Chem-Bar* and Pulpdent,† which may be used for this purpose, and no silicate filling should be inserted without using a calcium hydroxide liner. The milk-white film formed by these liners is very obvious and must be removed from the cavity margins before inserting the silicate filling. We no longer hesitate to insert the silicate filling at the same visit as the cavity is prepared when employing one of these liners. The pulp is adequately protected, there is seldom, if ever, postoperative discom-

* L. D. Caulk Co., Milford, Delaware.

† Rower Dental Mfg. Corp., Boston, Mass.

fort, and the liner does not obliterate the retentive features of the cavity or affect the physical properties of the silicate cement.

SELF-POLYMERIZING ACRYLICS

The auto-curing acrylic resins were very enthusiastically accepted as a restorative material by many dentists, to their later sorrow. A critical study of the physical properties of these materials would have predicted their failure in the mouth. Their coefficient of thermal expansion is over 7 times that of tooth structure and they contract during polymerization even when a laminated technic is employed. While early reports¹⁴ indicated that they were not harmful to the pulp, histologic studies¹¹ after acrylic fillings had been allowed to remain in the mouth for longer periods of time demonstrated localized abscesses and pulpal necrosis. The material itself is evidently not an irritant to the pulp per se, but the excessive percolation that occurs¹⁰ when they are submitted to cycles of thermal changes in the mouth acts as a pronounced insult to the pulpal tissues. A recent study in Sweden⁵ reported carious dentin under approximately 60 per cent of a large number of acrylic fillings that had been removed. Although the acrylics are not soluble in the saliva as is silicate, neither do they possess the anticariogenic property of the latter. This property of silicate has been attributed to the fluoride content of the material and Phillips and Swartz¹² have suggested the possibility of adding fluorides to the resin filling materials, but much clinical work remains to be done before such a restorative can be recommended to the profession.

No cavity liner or intermediate base can compensate for the deficiencies of acrylic as a filling material, and with the exception of their use in the fabrication of temporary crowns, they should be discarded from the operatory.

SILVER AMALGAM

Histologic investigations^{3,7,13} have proven amalgam to be well tolerated by the pulp, but clinical experience reveals frequent postoperative discomfort to the patient in response to thermal changes. For this reason intermediate bases are often used under amalgam fillings, especially when a large quantity of fresh dentinal tubules must be cut in the cavity preparation.

Zinc Cement and Eugenol

Zinc cement again has been the most popularly used material, but owing to the irritating quality of this material itself plus its inability

to eliminate the inflammatory changes that occur in the pulp as a result of the mechanical intervention of cavity preparation, it was suggested by the author⁶ that equal parts of eugenol be added to the commercial cement liquid. Zinc oxide and eugenol will eliminate these deleterious inflammatory changes when used either as a base or as the entire filling,^{3,18} but the mixture does not offer sufficient compressive strength to withstand the most effective packing pressure of amalgam. While the addition of eugenol to zinc cement does reduce the crushing strength, it is still close to that required by the A.D.A. specification. Zinc cement at its strongest is a poor foundation for the condensation of a well condensed amalgam filling, however, and more nearly perfect cavity preparations can be made when allowances for an intermediate base are not necessary.

Copal Varnishes; Calcium Hydroxide

Copal varnishes, while capable of reducing sensitivity to some thermal changes, are incapable of eliminating much of the common postoperative discomfort to patients with young teeth freshly filled with amalgam. Calcium hydroxide liners fall into this same category.

Gottlieb's Zinc Chloride and Potassium Ferrocyanide Solutions

In 1947 Gottlieb² introduced some solutions reported to reduce the incidence of caries when topically applied to the caries-susceptible areas of the teeth. Although this so called "impregnation technic" has been more or less discredited by the subsequent work of others, these solutions are capable of greatly reducing postoperative sensitivity to thermal changes in freshly filled teeth. The solutions used are a 50 per cent solution of zinc chloride followed by a 20 per cent solution of potassium ferrocyanide.

The Gottlieb Technic. A few drops of the zinc chloride are placed in a Dappen dish to which is added a couple of drops of a 1 per cent solution of Nacconal⁸ as a wetting agent to reduce the surface tension. A 1 per cent solution of Tween 20 (polyoxyalkylene) can also be used for this purpose, as I am sure could many other wetting agents. It is believed to be the organic component of the dentinal tubules that transmits the sensation to the pulp. The zinc chloride solution penetrates the tubules and coagulates this organic material by the liberation of hydrochloric acid. A saturated pellet of cotton is used for this application and the solution is actually worked into the cut tubules

* National Aniline Division, 40 Rector Street, New York, N. Y.

through a pumping action. A few drops of the potassium ferrocyanide are likewise placed in a second Dappen dish to which are added a couple of drops of the wetting agent. Zimmer¹⁹ has estimated that it requires about three times as much of the potassium ferrocyanide to neutralize the zinc chloride, and thus the cavity must be flooded with the second solution. Again a pumping action is employed. The potassium ferrocyanide precipitates the coagulum formed by the zinc chloride's action on the organic matter of the dentinal tubules and forms a white precipitate which is clearly visible to the operator. Owing to the self-limiting action of the two solutions, no irreversible reactions are caused in the pulp, and the organic roads of the dentinal tubules are blocked, either eliminating or substantially reducing thermal sensitivity in the treated teeth.

Some cases resist desensitization regardless of the technic and no scientific explanation for this resistance has been discovered, but fortunately these cases are very rare. Occasionally when the dentist is working without local anesthesia the patient may complain of discomfort when the zinc chloride is first applied. This can be quickly and easily alleviated by immediately applying the potassium ferrocyanide solution to the cavity. While such discomfort has been reported in the literature we have seldom experienced this clinically in our own practice. Gottlieb suggested that the cavity be immediately syringed with water if pain is experienced when the first solution is applied, but we have found that the immediate application of the second solution is just as effective in eliminating the discomfort and does not interfere with the completion of the desensitization treatment.

This strong zinc chloride solution has a definite caustic effect on the gingival tissues and this technic should be carried out under the rubber dam. The use of the dam is so indispensable to the performance of the highest quality of operative dentistry that this requirement should not complicate the technic whatsoever. After the application of the second solution and the formation of the white precipitate, the cavity is dried with clean cotton pellets and generous blasts of compressed air to regain the necessary dry field of operation. The margins are freshened and the restoration is built on the solid foundation of the dentinal floor of the cavity rather than against a possibly yielding cement base.

Phenol

Phenol has been used for decades by many dentists as a cavity sterilizing agent, and although cavity sterilization is virtually a myth—usually unattainable, if not unnecessary—the use of this caustic has

reduced the thermal sensitivity of many teeth. Gottlieb's solutions are much more effective for this purpose, however.

Intermediate Bases in Pulp Exposures

The only indication for an intermediate base beneath an amalgam filling is where there is an exposure or near exposure and the pulp needs to be protected from the pressure of condensation of the filling material. Kalnins' work⁶ suggests that pressure on exposed properly treated (calcium hydroxide) pulps favors healing by controlling the postoperative bleeding, rather than destroying pulpal tissue as long believed. Even accepting this research, we prefer to apply this pressure over a bridge of cement to avoid the possibility of packing amalgam into the pulp chamber.

COLD FOIL

Gold foil is still the restorative material of choice in selected cavities, and the development of proficiency with this material will invariably result in an elevation of the type of operative work done by the operator with all the other restorative materials. Foil, being a non-irritant, is well tolerated by the pulp. Postoperative sensitivity due to thermal changes and inflammatory reactions in the pulp due to the trauma of condensation can be eliminated by the Gottlieb method. Bases should be employed only to protect areas of exposure or near exposure of the pulp from the pressure of condensation. The use of the electro-mallet reduces this pressure to almost nil from a clinical standpoint.

After the formation of the white precipitate, the retention points should be re-established with angle formers and the margins of the cavity freshened with hand instruments of choice.

GOLD INLAYS

Cast gold is also a non-irritant, but sensitive recently restored teeth with inlays are a common occurrence in most practices. This sensitivity is frequently due to trauma during the cavity preparation or to the irritation of the pulp by saliva or a prodigiously expanding and contracting temporary stopping while the casting is fabricated in the laboratory. A zinc oxide and eugenol preparation, such as Pulpotec^{*} or Ward's Wondrpak,[†] serves as a much more benevolent temporary filling for the prepared tooth.

* L. D. Caulk Co., Milford, Delaware.

† Westward Dental Products Co., San Francisco, California.

Again we recommend the use of Gottlieb's solutions, however, when virgin dentinal tubules must be cut during the cavity preparation. When old amalgam fillings are replaced with inlays and there has been adequate opportunity for secondary dentin formation, this impregnation technic may not be required, but its routine use is a safety precaution in our office. The solutions should be applied at the same visit as the cavity is prepared and while the rubber dam is still in place. This will reduce the chance of irritation from either saliva or the temporary filling. Once more the margins of the cavity are freshened before either taking the impression or carving the wax direct.

When teeth are very badly broken down and require a restoration of a portion of the internal structure before the fabrication of the casting, zinc cement is contraindicated for this function. If this preliminary restoration is done in silver amalgam a much more substantial foundation for the inlay or crown is provided and the anticariogenic property of the amalgam is utilized. Sensitivity due to the difference in the electropotential of the gold and the amalgam is not a clinical problem when the Gottlieb desensitization technic has been employed. Faradic current can be set up in the amalgam alone if it is contaminated with moisture during condensation, thus providing another reason for the routine use of the rubber dam.

CONCLUSIONS

The dental pulp should always be protected from silicate cement by the use of a calcium hydroxide cavity liner. No liner or base has been advocated beneath self-curing resin fillings for we can not recommend the use of the present acrylic filling materials in operative dentistry. The only place for an intermediate base beneath amalgam restorations is to protect capped exposed or nearly exposed pulps from the pressure of condensation of the filling material. A desensitization technic employing two solutions has been described for use under amalgam, gold foil, and cast gold restorations which is clinically successful in a large majority of cases, does not detract from the perfection of the cavity, and does not affect the physical properties of the restorative used.

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Acrylic Resins in Prosthetic Dentistry

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The present high quality of prosthetic dentistry is directly dependent on the development of resins for making the restorations. Nearly all materials which can be molded in a temporary gypsum mold have been tried at least experimentally. Goodyear's discovery of vulcanite (1839) was the first break-through and for 100 years after the issue of U. S. Patent No. 8075 to him, hard rubber was the standard denture base material. Hyatt (1868), trying to find a substitute for ivory for billiard balls, discovered "celluloid" which was used later for denture bases. Since these, many resins have been used for denture bases, such as phenol-formaldehyde, glyptal, vinyl acetate-chloride, styrene, acrylics, and so forth, either alone or in combination with other resins.¹²

When acrylic resin (methyl methacrylate) was introduced as a denture material in 1937, almost immediately it became the most widely accepted material, and it still is. The resin has been very successful as a denture base and as a tooth material. It has fine esthetic properties, excellent color stability and chemical stability, and can be used with a simple technic for the construction of dentures.

The properties of acrylic resins are not ideal in all respects but the combination of virtues rather than one single property is the basis for their being so generally used. Recent developments have contributed to improved esthetics by more realistic coloring and "characterizing" the denture to give a more lifelike appearance. Methods of fabricating the denture designed to produce a more precise reproduction of the cast have been given much study. These have included several variations of the injection procedure for filling the mold. The German development and refinement of accelerators which lower the temperature of polymerization of the acrylic resin and make it possible to obtain satisfactory cures at room temperature have produced the most outstanding basic change in this material for denture use.¹

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Research workers have adapted other types such as styrene and epoxy resins to dental applications.

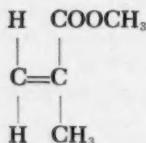
PHYSICAL AND CHEMICAL PROPERTIES

Denture Base Resin

The properties of acrylic resins used for denture materials have been the subject of many research reports from the National Bureau of Standards, dental schools, manufacturers, and individual dentists. American Dental Association Specification No. 12 and Federal Specification U-R-179 have been based on the results of these reports. The American Dental Association Council on Dental Research publishes in the *Journal of the American Dental Association* a list of materials which have been certified by their respective manufacturers to comply with these requirements and have been tested by the Research Associates of the American Dental Association. This makes available to the dentist a list of resin denture base materials of standard quality. The recently approved American Dental Association Specification No. 15 for Plastic Teeth will be used in a similar manner. This certification is strictly voluntary on the part of the manufacturer of the product. It informs the user that those materials listed meet the standards, and that the producer has obligated himself to keep his material up to the standard.

The chemistry of the acrylic resins is voluminous, as these resins are extensively used in the plastic industry. The essential factor for the dentist is that the monomer, a liquid, is such that when subjected to heat and/or the action of a suitable catalyst it will polymerize or cure to form a polymer which is a solid material that has the necessary physical properties to produce a denture base. The properties of the resulting denture base are dependent not only upon the formulation of the materials furnished but equally upon how it has been processed by the dental technician or dentist. Therefore, it is very important that the manufacturer give clear, detailed instructions on how to use the material and that the dentist follow the instructions precisely.

The chemical base formula for methyl methacrylate monomer is



The polymer is formed by breaking the double bond and attaching many monomer units together in a straight chain, similar to box cars

making up a train. Thus, the polymer is a macromolecule composed of the units of monomer chemically united to give a solid mass. The polymer can be produced by suitable controls to have a wide variety of chain lengths, varying from a few up to many thousands of units, resulting in molecular weights from a few thousand to several million. The mechanical properties are dependent upon the length of the polymer chains and the distribution of chain lengths in the finished material. The rate of polymerization or cure is affected by heat, light and chemical catalysts, such as benzoyl peroxide. The reaction is exothermic as it liberates about 80 calories of heat for each gram of monomer polymerized to the solid. The curing of the resin results in a higher density. The density of the monomer is 0.94 gram per cubic centimeter and that of the polymer is 1.18 grams per cubic centimeter; thus a reduction in volume occurs.

The acrylic resin denture base materials are usually not made of a single resin but more often are copolymers with such resins as ethyl methacrylate, ethyl acrylate, or mixed polymers of vinyl acetate-chloride and methyl methacrylate. Also styrene resins and epoxy resins have been developed for denture base applications. While all of these resins have some desirable properties, the methyl methacrylate is by far the most widely used.

The acrylic denture base material is available in two forms, (1) the powder and liquid, and (2) the gel or plastic cake. The first is most used, because it has a very long shelf life under normal storing conditions and temperatures. The liquid is stabilized by adding small quantities of chemical inhibitors such as hydroquinone. The gel form is ready mixed by the manufacturer and is more sensitive to storage especially where high temperatures are to be expected, unless refrigeration can be made available. The theoretical advantages of the gel are that it can be mixed under controlled conditions and allowed to age so that the monomer completely diffuses into the polymer grains; this process results in a more homogeneous plastic mass for packing the denture. This longer period for diffusion makes it possible to use higher molecular weight polymers that have higher strength than in the powder-liquid form. The fact that the user is not required to formulate the end product by measuring and mixing the powder and liquid, but only uses the cake as it is received, is an advantage. The dentist can expect good results from either form and his choice is dependent on the conditions under which he has to operate.

The physical properties most significant in a denture base material are strength, color stability, precise reproduction of the case, dimensional stability, tissue tolerance, and adaptability to a simple technic for fabrication. The available materials that meet American Dental Association Specification No. 12 provide the profession with materials

that will give good clinical results when properly used. The accuracy of reproduction of the cast should be improved. Recent methods of measuring the contour of the denture and casts will take a lot of guess-work out of the difference between what is called a good or a poor fit.⁶ These methods will replace opinions with numbers or, in other words, substitute quantitative data for qualitative evaluations obtained by looking at dentures on casts. Increased strength would be useful especially in partial dentures so that small sections could be used.

Plastic Teeth

Plastic teeth are widely used.¹¹ About 90 per cent of prosthodontists use them to some extent, but it is estimated that of the total number of teeth used in the United States approximately one-fifth are plastic and the rest porcelain. In some foreign countries the proportion of plastic teeth is higher. Methyl methacrylate resin is most used although some teeth are made from copolymers of vinyl and acrylic resins. The teeth are esthetically good since they can be molded and colored to any desired shapes and shades. They can be made to bond chemically to the bases. The low modulus of elasticity reduces "clicking" of the dentures, which is objectionable in some porcelain-teeth dentures. The two physical properties most criticized during the past 15 years in the use of plastic teeth have been low resistance to abrasion in service and crazing when dentures are rebased. In recent years crazing has been eliminated by the manufacturer by cross-linking the polymer.¹¹ The resistance to wear needs improvement if plastic teeth are to be more generally used, especially for cases where heavy occlusal forces are anticipated. American Dental Association Specification No. 15 for Plastic Teeth adequately defines tests for the properties of acrylic teeth and will be a standard for the dentist to use.

TECHNIQUES FOR PROCESSING

In this section only the essential factors in processing denture base resins will be discussed; details are omitted because of space limitations.

Heat Curing

To accomplish the most satisfactory heat curing, the following technique is recommended after the wax denture has been flasked and the wax removed by the usual process with hot water.

1. Wash out the flask with a hot detergent solution (one tablespoon of synthetic detergent to a pint of water) and rinse with clean hot water.⁷ This removes small traces of wax or residues from the wax that water alone will not clean from the teeth.

2. Mix the acrylic powder and liquid as directed by the instructions; be sure they are thoroughly mixed.

3. As a good index of when the liquid is diffused in the polymer sufficiently to make a good pack consistency, observe the time when the mix will free itself from the jar when stirred. Pack the denture and trial pack two or three times when using the conventional compressive flask, cutting away all excess on the lands each time. Close the flask *slowly* in a bench clamp, allowing time for the resin to flow into all the small crevices. DO NOT overpack or add excess for final closure of the flask. To do so will produce an open bite. High pressure is not needed; only small positive pressure in the final closure for metal-to-metal contact of the flask is required.

4. When the plastic-cake or gel form is used the flask should be warm to the touch. It can be placed in the curing bath immediately after packing. For powder-liquid type it is best to let the flask rest in the clamp under pressure for considerable time to allow the liquid to penetrate into the polymer particles before heating is started. One hour is a practical time but longer is better.

5. Cure the resin, either (a) by placing the flask in a constant-temperature water bath at $165 \pm 5^\circ$ F. for 8 hours or longer, or

(b) by placing the flask in a bath at 165° F. for $1\frac{1}{2}$ hours and then heating to boiling (212° F.) for 30 minutes.

The latter method (b) is preferable for very thin complete dentures or partials where the bulk of resin is small. The main item to remember in curing is that the process of polymerization is quite exothermic so that the resin should be heated slowly up to the critical range where the internal mass of the resin reaches temperatures much higher than the bath temperature. In general, the critical range is between 65° C. (149° F.) and 80° C. (176° F.); at this temperature the reaction is quite fast. Three to 5 minutes at these temperatures will effect most of the polymerization but not all. Longer time in the bath or higher temperature is required to complete the cure.

6. The flask should be cooled slowly from the boiling water temperature. Cooling overnight in the bath is ideal, but removing the flask and bench-cooling for 30 minutes, then placing in tap water for 15 minutes, is satisfactory. Do not remove the flask from boiling water and place it immediately in tap water; this rapid cooling causes warpage in the denture due to the differential thermal contraction of the resin and gypsum mold.

7. Deflask and polish the denture in the usual manner and keep it in water until delivered to the patient.

Self Curing

A self-curing denture should be processed in the same way except that the heating is omitted. In this type, the resin has had accelerators such as amines added to cure the denture effectively at room temperature. In general, the self-curing types are not quite as strong as the heat-cured resins because the polymerization is not as complete, but recent studies indicate slightly better fit due to less curing change, and the strength seems to be sufficient although full strength is not reached for several hours.

Injection Methods

Many injection processes have been devised for filling the mold.³ They produce equally good dentures, but in general the results are about the same as those by compression molding, according to the published data. The advantages of injection systems are attributed mainly to a more precise technic and better control of all stages of processing. High pressures are not desirable in denture molding because of the low physical strength of the temporary gypsum mold. This is a fundamental difference from industrial castings, which are made in steel molds.

FACTORS WHICH AFFECT FIT OF DENTURES

The fit of a denture is controlled by several factors. This discussion will be confined to the items concerned with the fabrication of the denture after the impression is obtained and the cast is available.

First the resin-filled mold is cured by heat or chemical reaction. This causes the resin monomer-polymer mixture to shrink in volume about 7 per cent for acrylic resin. The monomer or liquid phase changes from a density of 0.94 gram per cubic centimeter to 1.8 grams per cubic centimeter. The effective linear change (curing shrinkage) of the denture across the posterior section is about 0.5 per cent or 0.25 mm. for heat-cured acrylic resin and about 0.3 per cent or 0.15 mm. for self-curing resin. The reduction in size is not directly related to the curing shrinkage because the pressure on the resin causes it to conform to the cast until the resin is rigid.

The heat-cured resin probably conforms very accurately at the high temperature and the effective shrinkage is the thermal contrac-

tion of the resin from the temperature at which it is sufficiently elastic to resist distortion down to room temperature. A simple calculation supports this concept. For example, if the above temperature for a resin is 75° C. (167° F.) and the denture is cooled to a room temperature of 20° C. (68° F.) in the flask and the coefficient of contraction is 80×10^{-6} per degree centigrade, then 55°C. (the change in temperature) $\times 80 \times 10^{-6} = 0.44$ per cent contraction. This is very close to that observed by many studies.^{5,8-10}

The self-cured resin has less shrinkage because the cure is effected at a lower temperature.

Partial compensation is obtained by the fact that acrylic resin expands on the sorption of water at the rate of 0.23 per cent linearly for 1 per cent increase in weight of water absorbed.¹³

Denture bases made of acrylic resin expand when placed in water or in the oral cavity until equilibrium is reached. This is at 1.5 to 2.0 per cent sorption by weight. This amount of water will cause an expansion of about 0.3 per cent linearly and compensates for about one-half the curing shrinkage of heat-cured resin and essentially all the curing shrinkage of self-cured denture bases. Practically, the cast has a setting expansion of 0.1 to 0.2 per cent, so clinically, cases of heat-cured resins usually are slightly small and self-cured resins slightly large in dimension.

It is best to keep dentures wet at all times when they are not in service to insure maximum dimensional stability.

The variations in research reports on the exact dimensional changes in clinical cases due to water sorption are largely explained by the amount of water in the resin when the cure is finished. Recent investigations have shown that water sorption of polymethyl methacrylate resin is independent of molecular weight at all temperatures below 70° C. (158° F.).²

The distortion of a resin from stresses in service is dependent upon the mechanical properties of the resin, such as modulus of elasticity (a measure of stiffness), hardness of the surface and plastic flow.

In general, the values for the mechanical properties of resins are much lower than for the corresponding properties of metals. The modulus of elasticity is 0.3 to 0.5 million pounds per square inch (psi) compared with 11 to 15 million psi for casting gold alloys and 30 million psi for steel.

The surface hardness is 16 to 21 kilograms per square millimeter for denture base acrylic resins, which is very low compared to that of metals. The recovery from indentation of the surface is about 80 per cent, so the surface resists permanent distortion. The tensile strength⁹ of 8000 to 10,000 psi is much lower than that of alloys used

for denture castings but seems to be sufficient as measured by the small amount of breakage of dentures in service. The breakage that does occur is most likely to be from low fatigue strength. A few patients routinely break resin dentures after service for only a few months. The best solution for such exceptional cases is to use metal bases.

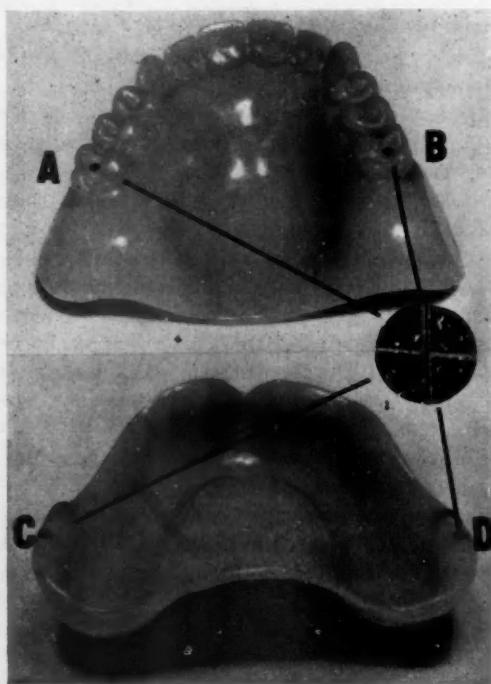


Fig. 1. Position of pins in dentures for observing dimensional changes in service. Distances AB and CD are measured with a comparator microscope.

The general opinion that dentures made of acrylic resins change a large amount in service has not been substantiated by measurements.

A recent report by Mowery et al.⁴ on a series of dentures in service made of both heat-cured and self-cured resins showed that dentures seldom change more than 0.2 mm. across the posterior section. Figure 1 shows the method of measuring and Figure 2 the results of the average changes over various periods up to 6 years of service. The graph indicates that well constructed dentures retain their size to within a few tenths of a millimeter after they are placed in service.

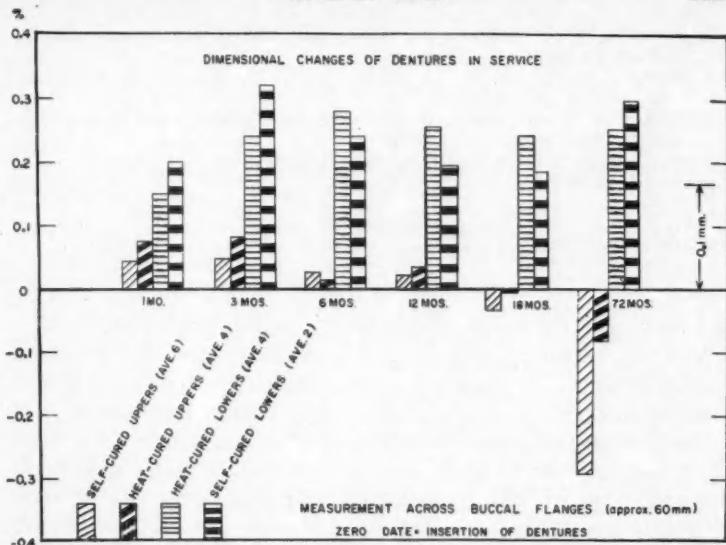


Fig. 2. Dimensional change of a series of acrylic resin dentures in service for 8 years.

This seems to support the idea that the loosening of the dentures should be attributed to tissue changes.

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Self-curing Resins in Restorative Dentistry

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The introduction and use of the self-curing resins has afforded the dental profession an excellent example of how knowledge, or lack of knowledge, can materially affect the use of and in turn the results that may be obtained from a dental material. Success or failure in most instances has been in direct proportion to the operator's understanding of the qualities and properties of the material as related to the problems of operative procedures. Knowledge of the chemistry, physical properties, qualities, characteristics, and manipulative procedures is therefore imperative if reasonably satisfactory results are to be obtained from use of the material.

CATALYST-ACCELERATOR CHEMICALS

The material used to form resin restorations today is basically a methyl-methacrylate monomer and polymer plus certain chemicals that bring about polymerization of the monomer portion of the mixes. Two types of chemical catalyst-accelerators are used in the self-curing resins. The first of these is the benzoyl peroxide-amine type,² and the second is the sulfuric acid-thionyl chloride type.^{1,6,14} The former requires more time to bring about gross polymerization than the latter; however, when polymerization has been completed, there is very little difference in the physical properties of the two types.

PHYSICAL PROPERTIES OF RESIN AS RELATED TO ITS USE AS A RESTORATIVE

Understanding and appreciation of the physical properties of the resin are most important if its qualities as a restorative and the techniques used with it are to be properly evaluated. The general information contained in Figure 1, which lists some of the physical properties

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PHYSICAL PROPERTIES OF RESIN

1. Solubility	.01 %
2. Modulus of elasticity	300,000 lbs./sq. in.
3. Hardness of resin (Knoop)	18-20
4. Thermal conductivity	Low
5. Coefficient of expansion -	

resin, 8×10^{-5} per degree C
tooth structure, 1×10^{-5} per degree C

Fig. 1. Some of the physical properties of self-polymerizing resin. (From Simon, W. J. [ed.]: Clinical Operative Dentistry. Philadelphia, W. B. Saunders Co., 1956.)

of resin, is of significance and will serve as a basis for most of the subsequent consideration of resin as a restorative.

Solubility

The low solubility of resin is one of its better properties when it is compared to cement and silicate. This is of particular importance in situations in which both good esthetics and the maintenance of mesial-distal dimension of tooth substance and space are of significance. This quality, however, has two possible disadvantages under certain conditions. Because of its low solubility, the loose resin restoration does not dissolve and fracture away as silicate does and thus may entrap destructive materials and solutions between itself and the tooth substance. Such a situation, regardless of the material which is loose in the cavity, usually leads to a breakdown of adjacent tooth substance. This danger may be prevented or minimized by having adequate resistance qualities in the preparation and by using application technics which will produce adequate apposition of the resin to the cavity wall.

The low solubility of the resin in mouth fluids makes leaching of incorporated anticariogenic agents from the material rather limited and possibly ineffective. Recently, some manufacturers have placed such agents in resin restoratives, but this practice is too new at this time for a thorough evaluation of its effectiveness. The lack of this anticariogenic quality, which has been attributed to amalgam and silicate,¹⁵ precludes the use of resins where such a quality is advantageous, as in mouths with a high caries index.

Elasticity; Hardness

The relatively low modulus of elasticity and low hardness of the resins are physical properties that must be recognized and accorded their fullest significance when using this material. Because of its low modulus of elasticity, resin should never be used in areas where the main criterion for success is the ability of the restorative to withstand load and its subsequent stress and strain. When the low hardness of resin (18 to 24 Knoop) is compared to that of gold (70 to 200 Knoop) and tooth substance (300 Knoop), it can be seen that the resins are relatively soft. For this reason resins should not be used where they will be subjected to heavy incisal or occlusal forces that produce wear and abrasive patterns.

The quality and extent of resistance and retention form incorporated in the preparation must also be correlated with these two properties of the resin. Inasmuch as resins have a low modulus of elasticity and low hardness, as well as a tendency to flow under load, it is imperative that resistance and retention form in the preparation not be slighted. Cavity walls, bases, and floors should be, as nearly as possibly, parallel and perpendicular to the basic loads and stresses to which the restoration and remaining tooth structure will be subjected. Cavity walls should be prepared so that there will be a maximum bulk of the resin at the margin. Because of the low modulus of elasticity and low values for hardness, feather edges or thin areas of resin doom such regions of the restoration to almost 100 per cent failure if they are subject to load, stress or abrasive conditions.

Thermal Conductivity

The thermal conductivity of resin is exceptionally low. It has been estimated at approximately one-fortieth that of metal restoratives.¹⁰ This quality makes resin a good insulating medium, and this material will do an excellent job of protecting the ends of the tubules and pulp from thermal irritation if it has been properly applied and maintained.

Thermal Expansion

The coefficient of thermal expansion of acrylic resin is seven to eight times that of tooth substance. This quality alone has caused many clinicians and investigators to question the use of resin as a restorative. The great difference between the coefficient of expansion of resin and

that of tooth substance is responsible for the phenomenon called "marginal percolation" (flow of water between restoration and cavity wall accompanying pronounced temperature changes) that has been observed around resins to a greater degree than that around other restoratives that have a lower coefficient.⁹ The full meaning of this phenomenon if not fully understood by the clinician or the laboratory investigator, for certain claims and assumptions derived from observations made under many varying conditions have resulted in confusing rather than clarifying the significance of marginal percolation. Clinically its significance in determining the success or failure of a restora-

TABLE 1. *Ratio of Thermal Dimensional Change of Various Restorative Materials to That of Tooth Structure*

MATERIAL	RATIO $\left(\frac{\alpha \text{ FOR MATERIAL}}{\alpha \text{ FOR TOOTH}} \right)^*$
Acrylic resin	7.1
Amalgam	2.2
Gold inlay	1.9
Gold foil	1.3
Silicate cement	0.8

* α = coefficient of linear expansion.

tion has not been demonstrated. Table 1 gives the thermal coefficient of various dental restoratives.

Polymerization Shrinkage

Regardless of the process used to induce polymerization, the acrylic monomer undergoes a volumetric loss of approximately 20 per cent during polymerization. This is known as polymerization contraction or polymerization shrinkage. Fortunately the powder portion of the mixes of resin used for restorations has already been polymerized and has undergone this shrinkage. Thus only the monomer portion of the mix undergoes shrinkage, which may vary from 2 to 10 per cent of the volume of material, depending upon the amount of monomer used to make the mix. This matter of polymerization shrinkage has caused considerable concern for both the laboratory investigator and the clinician, for it was recognized that a material which shrank this much would present a problem relative to its proper fitting and the sealing of the cavity. As a consequence, all resin application technics have as their basis some method, principle, or device which attempts to counteract or compensate for the shrinkage of polymerization.

METHODS OF APPLYING RESINS

Strip or Pressure Technics

Early workers in the field of resins advocated the use of small amounts of monomer and the application of pressure on the material in the cavity to control or minimize the effects of polymerization shrinkage on the adaptation and fit of the material to the cavity wall and margin. Such methods of application are called "pressure," "strip," or "bulk pack" technics and employ a strip or formed matrix upon which tension may be exerted. These methods, because of their simplicity and efficiency, are practical and may give reasonably satisfactory results when properly used. The basic principle is that of exerting pressure on the already inserted polymerizing resin by drawing a matrix strip or other type of matrix tightly about or upon the resin. The resulting pressure is supposed to force excess resin into the cavity to take up the void created by the polymerization shrinkage of the resin in the cavity. Unfortunately, in this type of operative procedure it is impossible to produce a confining wall which will confine excess material and force it into the cavity. When using a strip matrix or a bulk pack pressure technic, the excess fluid resin, which is placed in the cavity to form the restoration, is forced to the outside of the cavity and forms a flash. Whatever pressure there may be exerted from the matrix is then expended on the surfaces of the tooth and not upon the resin making up the restoration.

Apparently the satisfactory results obtained from so-called pressure technics are not due to confining pressure but to other factors such as the pattern of contraction, mechanical locking of the material to cavity walls and the presence of excess material from which the contracting resin may draw. The pattern of polymerization contraction within the cavity and the adhesion of the material to the cavity walls, and not the volumetric loss of polymerization contraction *per se*, are the key to successful adaptation of resin for pressure (bulk pack) technics, or for that matter for any other technics with resin. These phenomena have been observed by Nealon⁸ and others,^{3,11} and no doubt they explain why fair to good adaptation and margins may be obtained with resin even though there is considerable volumetric loss due to polymerization shrinkage. These phenomena also explain the paradox that restorations made of thinner mixes (that have, by the laws of polymerization, a greater volumetric loss) have also better adaptation of the material to the cavity walls, better retention, and better apposition at the margins. The reason is that the thinner mixes, which have lower viscosity and lower surface tension, tend to flow into the minute

roughnesses and crevices of the cavity wall surfaces and there polymerize to form small mechanical locks which hold the resin in close apposition to the cavity wall during the polymerization contraction. This causes a "pattern of contraction" to occur which draws upon the material in the unconfined areas of the resin making up the restoration, which is usually the surface excess of the material.

The so-called sealing primers or adhesives for restorative and cementing resins that have been introduced and advocated by many of the manufacturers are merely an adaptation and application of these previously discussed principles to improve adhesion and apposition of the resin to the cavity wall and to other restorative materials. Swartz, Phillips, Day and Johnston have demonstrated superior apposition or adhesion following the use of such agents,^{12,13} and as a result most workers and clinicians in the field of resin advocate their use.

Technics for applying resin may be either the so-called pressure or bulk method or any one of the numerous non-pressure technics which go under the synonyms "flow," or "brush-bead," "compensating," "neutralizing," etc. It is interesting to note that the success of any one of these relies upon the two principles already discussed to control the effects of polymerization contraction and to secure adequate apposition of the material to the tooth substance.

Non-pressure Methods of Applying Resin

Many operators are using the so-called non-pressure methods of applying resin to the cavity for the fabrication of restorations. Such methods rely upon two principles as a basis of their practicability: (1) thin fluid mixes with sealers or primers for superior adaptation as well as control of polymerization contraction, and (2) subsequent additions of resin to fill in the area of polymerization contraction. The brush-bead method of Nealon⁸ and the flowing of multiple increments of resin⁹ are the two most popular non-pressure technics being used today. The use of the brush-bead method is limited to the peroxide type of resin; the flow method may be used with either type of resin.

The flow method uses a thin to medium-thin mix of resin which is prepared and carried to the cavity on a trimmed 00 sable brush. This is touched to the base of the preparation and allowed to flow into the retention until about one-third of the cavity is filled. At subsequent intervals additional slightly thicker mixes are flowed into the cavity until it is filled to the margins and a slight excess is humped in the center surface area. The surface is then covered with a heavy oil to stop surface evaporation until the initial polymerization is completed.

Trimming of the excess and finishing of the restoration are performed according to the time necessary for polymerization.

The non-pressure technics are easily managed in class V cases and open areas where excess may be controlled. In certain areas the pull of gravity on large amounts of resin while it is fluid makes it very difficult to control the material and produce the desired form of the restoration.

Combination Technic

A combination technic using both a non-pressure and a bulk pack application to fabricate the restoration may be used in many cases. A non-pressure application of resin is used to secure maximum retention and apposition on the inner third of the preparation, and a bulk pack-strip matrix technic is used for the remainder of the restoration in order to obtain efficiency, control and contour. The non-pressure technic assures adaptation to the retentive areas and cavity walls; the bulk pack, if properly done with a contoured and confining matrix, assures proper contour and contact with a minimum of time and effort.

ESTHETIC QUALITIES OF RESIN RESTORATIVES—DISCOLORATION

The esthetic results that can be obtained early in the life of the resin restoration are exceptionally high, for this material more nearly matches the color shades and translucency of teeth than any other. If it were not for this desirable color factor and its low solubility, resin would have relatively little indication as a restorative. Unfortunately, the fact that under certain circumstances this favorable esthetic quality is not as permanent as it should be has resulted in considerable disappointment to both the clinician and the patient. Color changes and a tendency to darken with age have been observed in resins and reported by both the clinician and the laboratory investigator. Such reports are most beneficial in understanding and evaluating the significance of this problem.^{3-5,7} Exposure of direct filling resins to certain parts of the light spectrum results in color changes within the material. This has been attributed to chemical reactions of the accelerator-catalyst and to the effect that certain types of light have upon the products of these reactions.^{4,5} This was particularly true of the early benzoyl peroxide type resins before the development of the so-called color stabilizers. Clinically it has been observed that discoloration is almost in direct proportion to the type of resin used

(whether color stable or not) and the extent to which the restoration is exposed to light.

The observance of the following points will help to alleviate the discoloration problem when using resins:

1. Use a resin with as low a discoloration index as it is possible to obtain.
2. Place as little of the restoration as possible in areas of the mouth where there is exposure to sunlight.
3. Place as much of the restoration as possible above or below the lip line in order to reduce exposure to light.
4. Point out to the patient that the material is subject to discoloration, and make this problem primarily his responsibility. In the average mouth, discoloration of resin restorations by tobacco and lipstick has not been observed to be any greater than that of cement restorations.
5. Use as little monomer as possible to produce the desired working consistency.
6. Exercise complete and full toilet of the cavity to prevent contamination. Contamination of the cavity walls and resin not only reduces the apposition of the material but also aggravates and accentuates the discoloration factor. Rubber dams and complete isolation are a must for proper insertion and protection of the direct resins.

The new color-stable and sulfinic acid types of resins appear from a clinical evaluation to have considerably less discoloration over a period of time than did the early peroxide resins. This, however, does not mean that they are free from this problem. Proper trimming, finishing and polishing of the restoration will aid in maintaining good esthetics, for such procedures will reduce the tendency of chromogenic materials to collect along the margins and over the body of the restoration.

AN EVALUATION OF PROPERLY PLACED AND FINISHED RESIN RESTORATIONS

Unfavorable comments (aside from those concerning discoloration) that have been in many instances merely inferences and completely out of proportion to their actual significance, have contributed to the development of certain adverse opinions regarding the use of direct filling resins. Success or failure with resin usually depends upon knowledge or lack of knowledge relative to the material and its associated technics, and upon the application or lack of application of basic operative principles. Failure to consider these factors when evaluating resin, or any other material, has resulted in much of the misunderstanding and confusion concerning the merits, advantages, disadvantages, etc., of materials and the technics with which they are

used. The following conclusions regarding the resin restoration are based upon an evaluation of many thousands of cases in which the operators attempted to apply knowledge and basic principles toward obtaining the best possible results from the use of resin.

1. Properly placed resin restorations cause no more postoperative complaint and subsequent pulpal deterioration than do other restoratives. It is not the resin per se that produces such complications, but other factors. These are minute exposures, previously involved pulps, poorly adapted or loose restorations and operative trauma. To prevent these factors from producing unsatisfactory results it is most important that the operator render a complete and thorough diagnosis of the

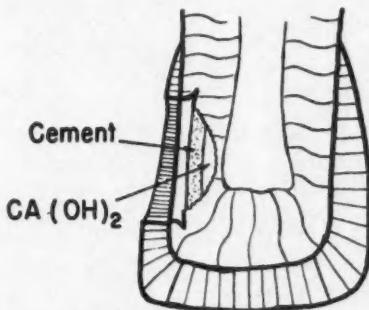


Fig. 2. A calcium hydroxide and cement base protects the dentin and pulp from chemical and thermal stimuli and, because of the rigid base, stops stress and strain stimuli.

condition of the teeth being treated and then take every precaution possible to prevent injury and irritation to the dentin and pulp during the operative and restorative procedure. In all cases where the base, pulpal, or axial wall is deeper than 0.5 mm. inside of the dentino-enamel junction or where the apex of the carious cone is considerably deeper, calcium hydroxide liners and cement bases should be used in order to prevent subsequent irritation of the ends of the dentin tubules in the deeper aspect of the cavity, and of the pulp. Figure 2 shows in diagram this precautionary and protective procedure.

2. The early and subsequent esthetic qualities of the resin restoration range from excellent to only fair. These qualities depend basically on color stability, which, as was pointed out, is mostly contingent upon selecting a resin with a low discoloration index and upon using it in an environment which will produce a minimal amount of discoloration. The newer resins, if properly placed and finished and not exposed to too much of the light spectrum, are in most instances satisfactory so far as their esthetic qualities are concerned.

3. Excellent form, contour, and contact can be obtained and maintained with resin when it is properly used to fabricate anterior restorations. Contoured and confining strip matrix technics used with a separator for class III restorations assure full contour and contact, which, because of the low solubility of the resin, are maintained indefinitely. The class V restoration also maintains its contour because of the low solubility of the resins.

4. Marginal percolation in properly placed and finished restorations has not been found clinically to be of any significance. Removal of

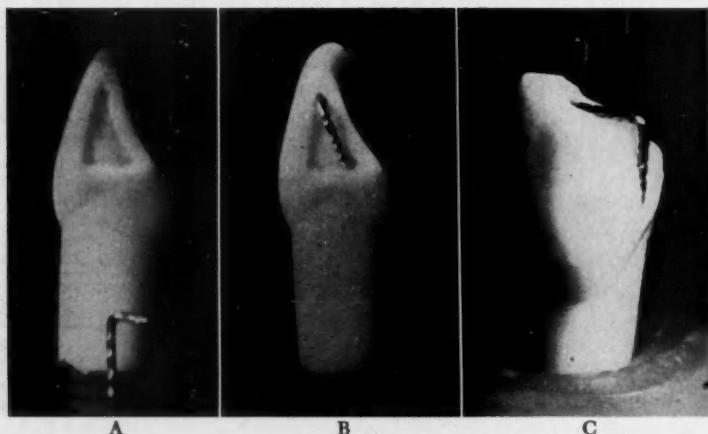


Fig. 3. Preparations and reinforcing wire for class IV resin restorations.

properly placed resin restorations has demonstrated firm solid tooth substance adjacent to this material. A loose resin restoration, like a loose restoration of any other material, usually has broken-down tooth substance associated with it. This, however, is not due to percolation but to the pumping of fluid and debris between the material and cavity walls that results from movement of the loose filling. This phenomenon occurs under all loose restorations and is not peculiar to resin.

Low hardness and low modulus of elasticity are properties of resin which makes its use inadvisable in areas of load stress and abrasion. If, because of certain conditions, resin must be used in areas where load stress and abrasion are going to be greater than the material can withstand, it is advisable to use some form of auxiliary support and retention. The use of devices such as reinforcing wires or castings which dissipate stresses throughout as large an area as possible minimizes their effect upon the resin. Figure 3 shows how a 0.020

inch stainless steel notched wire can be formed and used as auxiliary support and retention for class IV resin restorations. Figure 4 shows two fractured central incisors which have been restored with the reinforcing wire technic to produce very satisfactory esthetic results.

When incising loads are exceptionally heavy, window-type inlays with resin veneers will afford adequate resistance and retentive quali-

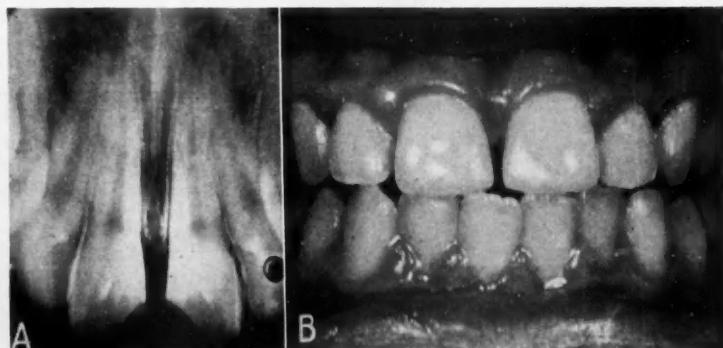


Fig. 4. A, Fractured incisors. B, Esthetic results obtained with resin and reinforcing wire technic.

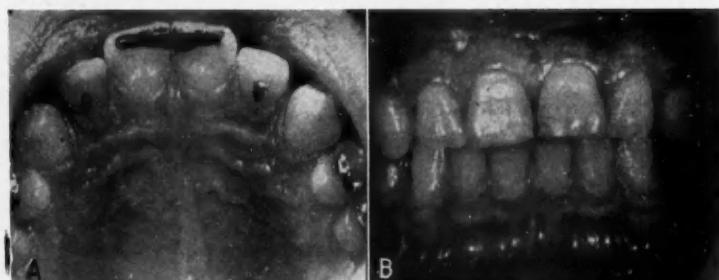


Fig. 5. A, Lingual view of inlays for class IV resin restorations. B, Labial aspect shows esthetic results for use of resin veneers.

ties and produce exceptionally good esthetic results. Figure 5 shows the lingual and labial aspects of such restorations and demonstrates the gratifying esthetic results obtainable by such restorative procedures.

CONCLUSION

To obtain reasonable success from the use of resin it is of the utmost importance that the operator know and understand the material as

well as the procedures that will produce satisfactory results. No material can be expected to be better than its physical properties. Misuse and abuse will lead to failure. Understanding and application of knowledge will lead to success in proportion to the ability of the operator and the properties of the material.

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The Wax Pattern

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Wax variables are probably the greatest material obstacle to accurate reproduction of cast restorations. Many of these variables are inherent and inevitable, but they may be minimized and controlled to a high degree by full knowledge of their existence.

Wax may contribute to the inaccuracy of restorations in seven different ways: (1) by distortion caused in removal of the pattern from the tooth or die; (2) by the high coefficient of thermal expansion of wax; (3) by the tendency of wax to warp from internal strains and elastic memory; (4) by the resistance of wax patterns to the combined hygroscopic and setting expansion of the investment mold as it sets; (5) by the use of excessive lubricant; (6) by the interference with accuracy and the surface character of the mold by wax residues; and (7) by injury to the mold resulting from the methods of wax elimination.

Each of these seven problems and their control will be discussed in turn.

DISTORTION IN REMOVAL OF PATTERN

Too soft an inlay wax will allow distortion while removing the pattern from the tooth or from the die at mouth temperature. Chilling a soft wax in an attempt to harden it against distortion during removal will cause the surface to shrink and will set up strains and distortions. Therefore, it is best to use a wax which is hard enough to be sufficiently firm at mouth temperature so that it will fracture rather than bend if there is an undercut or if the pattern is mishandled. If an excess of wax is desired past the finishing line into a slight undercut, such as the desirable extending of the margin of a full crown to provide a bulk of gold for finishing, this little extension can be built by luting soft casting wax to the harder inlay wax. The soft wax addition will bend rather than fracture, yet will not distort the pattern itself as it is removed from the die or tooth. Any wax pattern should be

allowed to reach mouth temperature gradually. Chilling a pattern rapidly will increase strains and distortion.

A small pattern such as a class V may be removed safely by its sprue former after luting the sprue former to the center of the pattern. A tubular sprue former will attach to the wax more securely than a solid one because the wax is displaced and will rise up the lumen. A tubular stainless steel sprue former holds but little heat and so causes

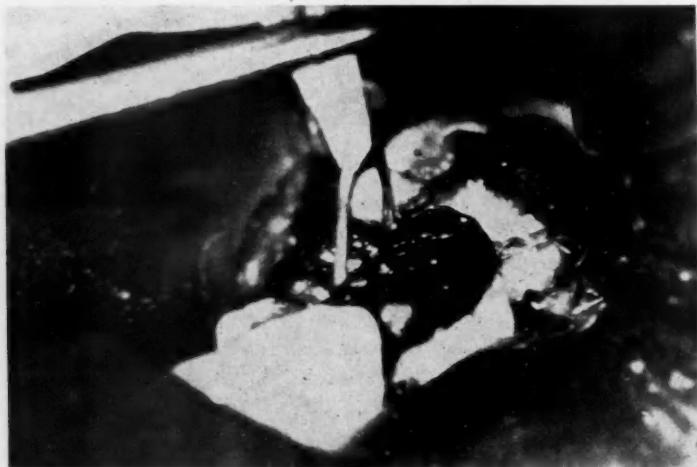


Fig. 1. A staple made from 22 gauge high carat gold wire serves as a handle for removing the wax pattern from the tooth or die. Dento-tape looped through the staple allows pattern withdrawal in the line of draft with a minimum of strain.

a minimum of wax distortion. For three-quarter crowns and pinlays, the tubular sprue former should be cut at a 45 degree angle to engage the lingual surface of the pattern. Then it can be attached in the direction of draft for easy removal. Since steel is a poor conductor of heat, even a short tubular steel sprue former can be comfortably held in the fingers for attachment to the pattern. Such a short heavy sprue of $\frac{1}{8}$ inch diameter positions the pattern desirably in the center of the mold,⁵ and utilizes the gold left in the crucible as a reservoir to prevent shrinkage porosity in the casting. (Phillips and Mumford⁶ have shown that only the center of the mold will produce an accurately compensated casting.) Stainless steel tubing for sprue formers is available from dealers handling orthodontic supplies.

A complicated pattern, such as an MOD, can best be removed from the tooth or die by luting a staple to the pattern, then removing the

pattern by means of dental floss or tape looped through the staple (Fig. 1). The pattern can then be held by the staple while the sprue former is attached (Fig. 2). A staple made of a high carat 22 gauge gold may be left on the pattern when invested. The gold will unite securely to the staple when cast. The staple thus serves as a handle for fitting the casting to the tooth or die (Fig. 3). To remove any pattern with an explorer invites distortion of the pattern.

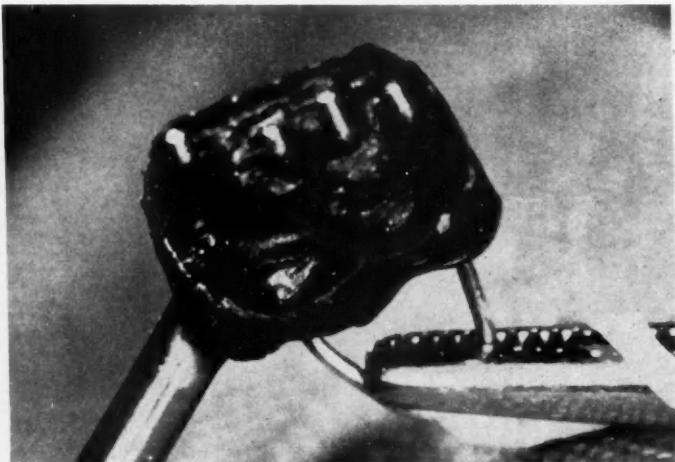


Fig. 2. The staple serves as a handle for holding the pattern while the sprue former is being attached. In this case, the pattern has pins for retention to a fractured molar.

THERMAL EXPANSION OF WAX

The coefficient of expansion of wax is so high that in the early days of castings, wax expansion was used to compensate for both gold and mold shrinkages. Complete success was prevented because of marked wax warpage, since the technic required a temperature of 120° F. while the mold was setting. Unless the dimensional change of a wax pattern from *room* temperature to *mouth* temperature is controlled or compensated for, an 0.8 per cent error in the size of the finished restoration must be expected.⁵

The best method for compensating this error is to allow the investment to set while the pattern is held at the same temperature at which it was made. This can be accomplished by placing the casting ring with its pattern into a water bath at 100° F. immediately after investing. The setting time of the investment *must* be slow enough to allow

the pattern to reach the water bath temperature before the initial set of the investment occurs. A minimum 8 minute initial set can be tolerated for the conventional size inlay ring, which takes 50 grams of investment. The ring should remain in the water bath until the mold is set, at least 30 minutes.²

There are two other ways of compensating for wax pattern shrinkage, from fabricating to room temperature, plus the inevitable gold shrinkage from the molten to the solid state:

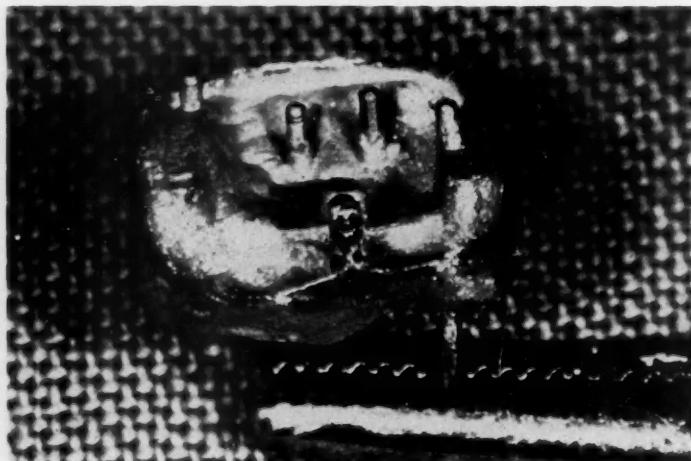


Fig. 3. The gold unites to the wire when cast. Thus the staple conveniently remains as a handle for fitting the inlay. The 22 gauge wire leaves but little blemish on the occlusal anatomy when it is removed.

1. Using a high thermal expansion investment of straight cristobalite, wax shrinkage from fabrication to room temperature (plus gold shrinkage) can be compensated against the thermal expansion curve of the investment. Unfortunately, straight cristobalite is soft and weak, producing a mold that is easily damaged by the turbulence of the gold when cast.

2. The so-called hygroscopic compensating technic, using an investment with a high hygroscopic expansion factor to which a controlled amount of water is added immediately following the investing process, may be used. Again the wax shrinkage differential must be matched against the thermal expansion curve. (The distortions common to the hygroscopic technic are discussed later in this article.)

WARPAGE FROM INTERNAL STRAINS

Direct Patterns

Inaccuracy caused by warpage from strains in the wax may be minimized for direct patterns by storing the inlay wax in a wax annealer at 120° F., which will release the strains inherent in the mass.⁴ A stick or cone of wax is taken from the annealer and the end is flamed, making it more fluid in order to copy detail. The flamed end is then pressed forcefully into the cavity, confined by a stable matrix. Firm, steady pressure should be maintained on the wax until it has reached mouth temperature. This will keep wax flowing into the cavity and will help control the tendency of wax to form a spheroid. Time is saved by having inlay wax already softened, ready for use, in an annealer. Holding can be done with the finger, or by having the patient bite, being sure that the matrix does not interfere. Where a rubber dam is used (most desirable for a direct technic), the rubber dam clamp, if any, can be slipped off quickly before asking the patient to bite. The rubber will offer little interference. The patient can be instructed previously to make lateral and protrusive movements and then to hold firmly. If the matrix is stable and well contoured, a minimum of finishing will be needed to perfect the pattern. The surface is carved and perfected with as little manipulation as is possible to minimize the residual strain.

A gold inlay can be made to reproduce dental anatomy faithfully with minimal effort because wax lends itself to easy building and sculpturing. Full advantage should be taken of this quality because the health of the investing and supporting tissues in the mouth depends upon correct dental anatomy of the teeth. Wax is best carved with a dull instrument, such as a No. 23 explorer for margins and a No. ½ or No. 3 Hollenback carver used as a scraper rather than as a knife. A *slight excess of wax should be left on all margins*. This provides the stock of gold necessary for finishing to the tooth, rather than cutting the tooth to fit the inlay. With burnishable golds (those with a Brinell hardness of 84 or less), gold can be spun to the tooth or to an accurate metal die, producing a fit like that of gold foil. This is done with semi-sharp round burs and finishing burs lubricated with petro-latum and with the University of Michigan burnishing instrument (SSW-5S). Burnishable gold alloys are most desirable for routine inlay use wherever enough bulk of gold can be provided to supply adequate strength. The carved pattern is polished by cotton moistened with warm water. Contact may be freed with a split strand of Dento-

tape. Then the proximal surfaces are polished with a strip of silk ribbon or rayon binding tape. A little time spent in perfecting a pattern surface is more than saved in finishing the inlay. The pattern is removed with the 22 gauge gold wire staple as previously described. A direct inlay is best cast with its contacts properly contoured but slightly open, to be perfected later with solder.

Hollenback¹ has shown that any inlay can be seated more completely and will have better fitting margins by routinely etching the cavo-surface, except for a 1 mm. band inside the margins. This is done by masking the margins and exterior surface of the warmed inlay with wax, and suspending the casting in aqua regia on a waxed Dento-tape. A 15 minute etching with a fresh solution at room temperature will remove a demonstrable 0.001 inch of gold from the exposed surface. Seating is done with heavy hand pressure, plus vibration created by light, rapid malleting. The masking wax for etching is composed of $\frac{1}{3}$ portions each of inlay wax, carding wax and sticky wax.

The first contact of an MOD inlay is soldered with 20 K solder and is shaped and polished. Then the second contact is built with 18 K solder so as not to melt the first contact. Contacts that are too tight can move other teeth into traumatic interference. Contacts that are too loose or are improperly placed will cause food impaction. The size and shape of a contact area and the shape of the embrasures are most important. It is well to copy normal contacts and embrasures found elsewhere in the mouth of the patient.

Indirect Patterns

Indirect patterns are best flowed onto a warm die. Working wax over a thermostatically controlled heating pad under a warm light in a zone of warmth comparable to mouth conditions will produce the best results in the indirect technic. Patterns should be invested *immediately* after their removal from the tooth or die because the inevitable strains caused during fabrication immediately assert themselves and initiate pattern warpage. Although it is recommended that patterns *never* be stored before investing, keeping them in a refrigerator will minimize their distortion.⁴ If indirect patterns must be stored on a model for a time, their margins should be perfected just prior to investing, or the pattern can be effectively re-adapted to the die in a water swager. Each brand of wax will have a critical optimum swaging temperature, near 114° F., which must be determined by trial and error. The swager should be kept in water at that temperature for a time prior to each use. The pattern on its lubricated die is wrapped

in a piece of thin rubber dam tied with Dento-tape so as not to leak water, and is subjected to hydraulic pressure created by standing on the plunger of the swager for one minute. The correct temperature will cause tiny creases to form on the surface of the pattern where folds have occurred in the rubber dam, but will not otherwise damage its shape. These minute wrinkles may be polished off the wax or can be easily polished off the gold casting itself.

With an accurate, silver plated die, it is possible not only to fabricate an indirect pattern, but also to finish completely the casting out of the mouth. This method has a distinct advantage for full crowns and complicated inlays, which often have margins that are inaccessible to finishing in the mouth. Unfortunately, it is more difficult to build a wax pattern on a metal die than on a stone die, because the metal tends to cool the wax rapidly, even when working over a heating pad, and pulls away the margins. The water swager is indispensable for re-adapting such a pattern. By the routine use of a water swager, a highly accurate pattern and casting can be completed on a metal die. With Thiokol impressions, a stone die can be poured and removed as soon as it is set. The same impression can then be silver plated. Waxing can be done largely on the stone die and the finishing on the metal die.

DISTORTION CAUSED BY RESISTANCE OF THE WAX PATTERN TO HYGROSCOPIC AND SETTING EXPANSIONS

Both hygroscopic and setting expansions of the mold are resisted by the wax pattern during initial setting, and are a varying source of distortion with all present investments.³ In effect, the gingival margins of an MOD inlay will be forced apart by the mold expansion while the occlusal bar of wax resists expansion at early stages of setting. The finished casting will thus pinch at the axiopulpal angles while the gingival margins will stand away from the tooth. This form of distortion is excessive with the so-called hygroscopic expansion technics. It can be minimized by using investments and methods producing the least possible combined setting and hygroscopic expansion. Hygroscopic expansion can be minimized by not permitting water to contact the investment while in the water bath. This is accomplished by keeping the water level just below the top of the ring. An investment composed of 17 grams of cristobalite and 33 grams of Gray investment, spatulated with 15½ cc. of water, raised to and held at 1100° F. for 15 minutes in the burn-out, will have the best properties now available in commercial investment.⁵ The Whip Mix Company packages such a product under the name of "Denver Investment."

It is designed to set slowly enough for water bath compensation even when spatulated mechanically, which is most desirable.

EXCESSIVE LUBRICANT

A lubricant is necessary to prevent adhesion of the wax to the tooth or the die. Since no two materials can occupy the same space at the same time, excessive lubricant will cause poor pattern adaptation to the cavity. Therefore, excess lubricant should be blown out of angles and from the intricate detail of the cavity or model prior to inserting the wax. Good commercial lubricants are a rather new development which aids materially in pattern fabrication.

INCOMPLETE BURN-OUT

ADA approved waxes have a minimum of nonvolatile residue. Incomplete burn-out of pattern wax, however, may prevent the margins from casting sharply or may cause back pressure to the flow of gold into the mold with incomplete castings resulting. Such casting failures usually present very shiny surfaces. For a standard 50 gram size ring, heating the mold to 1100° F. and holding that temperature for 15 minutes assures a complete burn-out and insures that the center of the mold has reached 1100° F. and a known thermal expansion.

IMPROPER WAX ELIMINATION

Wax elimination by water or with solvents will etch the surface of the mold to produce rough castings. Placing the mold in a hot oven or raising the temperature rapidly enough to boil the water and wax, rather than evaporate and volatilize these materials passively, will cause a roughened mold surface and a rough casting. The placing of the mold into a furnace not warmer than 200° F. is recommended. The wax then will melt and soak passively into the mold material and run out the sprue hole, which should always be down. It is well to set one edge of the inlay ring on a bit of china or plaster to allow the mold to "breathe." After the moisture content has been vaporized, the furnace heat can be increased rapidly to 1100° F. at which temperature it should be held constant for a minimum of 15 minutes.

Some additional reasons for rough castings primarily associated with the wax pattern itself are as follows:

1. Pattern surfaces not smooth and polished or not well adapted to the cavity.
2. Saliva, blood, tooth chips, or other debris on the pattern.

3. Leaving a detergent on the surface of the pattern after washing, particularly one that interferes with setting of the investment. Vel kitchen detergent has been suggested by Selberg as being effective and not affecting the investment adversely. All detergent should be rinsed off the pattern.

4. Investing a wet pattern. The pattern should be dried before investing.

5. Vibrating the mold excessively after investing. This may bring water to the surface of the pattern, producing a rough mold.

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Hygroscopic Investment Expansion for Small Castings

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AND

S. GUY HALL, D.D.S.**

All of the materials entering into the process of making an inlay are subject to volumetric change. Unless the physical properties of these materials are known and understood it is practically impossible to use them to advantage in the production of precision castings.

For many years following the introduction,⁹ by Taggart in 1907, of the cast gold inlay, very little was known about the physical properties of waxes, golds and investments. Only after a Fellowship was established at the National Bureau of Standards by the American Dental Association in 1929 was an investigation started which led to a better knowledge of them and later to specifications for their production.

The property of hygroscopic expansion in investments was first introduced to the dental profession in 1932 by Carl Scheu,⁶ and it is this type of investment expansion that will be discussed in this chapter as a means of compensating for the variables of wax shrinkage and gold shrinkage in making dimensionally accurate dental castings. It is not the intention of the authors to enter into a lengthy discussion of inlay wax and casting gold, but for one to understand the great advantage of a hygroscopic expansion technic it is first necessary to understand the problems involved.

INLAY WAX

Inlay wax is the least understood and the most variable of all the materials involved in the casting process, both because of its reaction

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to thermal change and because of its tendency to distortion. Investigations are now going on in search of a better material for this purpose and it is hoped that one will be found which will be less critical. Many writers refer to the casting problem as one of compensating for the casting shrinkage of gold, but inlay wax is a major variable and it must be considered as part of the problem.

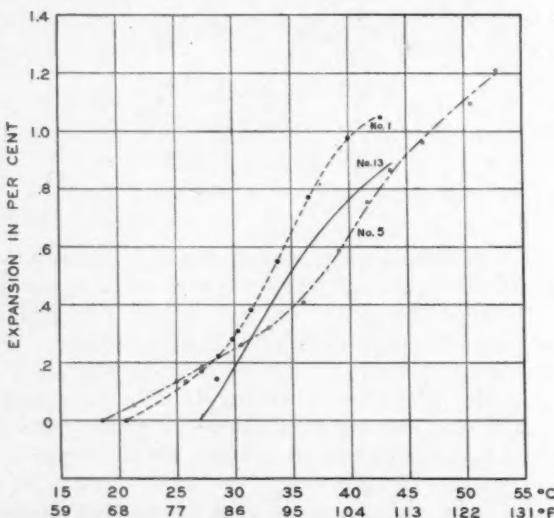


Fig. 1. Thermal expansion of a soft wax (No. 1), a hard wax (No. 13), and a medium wax (No. 5) of the A.D.A. specification type. (From Souder, W., and Paffenbarger, G. C.: National Bureau of Standards Circular C 433.)

Wax changes size when it is subjected to a change in temperature. This change amounts to approximately 0.02 per cent for each degree F. of temperature change, as shown in Figure 1.

The research workers at the National Bureau of Standards, when writing a specification for inlay wax, realized that dental operators might not always prepare cavities free from undercuts and that a wax still soft at mouth temperature would distort when withdrawn from such a cavity. Therefore, one of the requirements of the specification was that the wax must get hard above mouth temperature. Medium inlay wax has a minimum flow point of 106° F. and hard inlay wax has a minimum flow point of 113° F. (Fig. 2); if the wax is removed from an undercut cavity the pattern will fracture instead of distorting. Another point is involved in this characteristic of inlay wax: If the flow point is 106° F., then the wax cannot be compressed after

it reaches that temperature by any means available to the dentist. Open-mouth temperature in a patient is 95° F., so after the wax reaches 106° F., beyond which temperature it cannot be compressed, it quickly drops to 95° F., with a resultant shrinkage. When the pattern is completed and removed to room temperature the wax quickly assumes that temperature, with still further resultant shrinkage. This

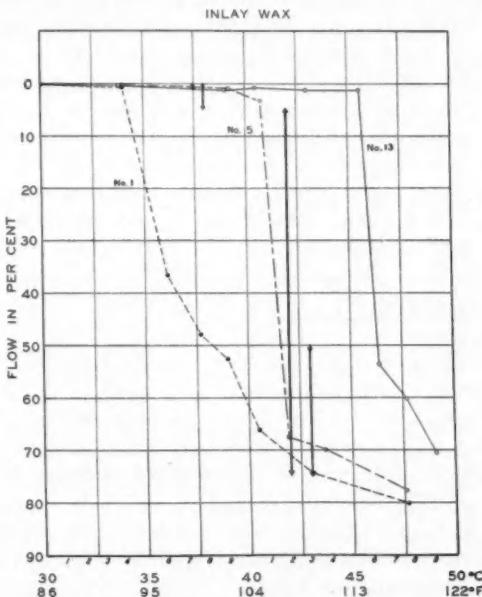


Fig. 2. Flow of a soft (No. 1), a medium (No. 5), and a hard (No. 13), inlay wax. (From Souder, W., and Paffenbarger, G. C.: National Bureau of Standards Circular C 433.)

discrepancy must be given consideration in any technic that has dimensional casting as its goal.

CASTING GOLDS

Casting golds contract on the average of 1.2 per cent plus or minus 0.2 per cent when solidifying.^{4,7} This figure fluctuates with the various formulas, reaching a maximum of 1.74 per cent with pure gold. It does not seem practical to change the casting technic to accommodate all of the various formulas, but this contraction should be recognized as a slight variable and some increased expansion should be allowed for those alloys that are high in gold content.

Recognizing the variables of wax and gold, the problem then is one of selecting an investing technic that will compensate for these discrepancies.

HYGROSCOPIC EXPANSION

Although several theories have been set forth as to the exact reaction which takes place to cause hygroscopic expansion in an inlay investment, none has completely explained it and there are many points yet unanswered. In 1932, when Carl Scheu⁶ first presented his findings on hygroscopic expansion as a part of a symposium by Coy, Phillips and Scheu before the ADA meeting of that year, it attracted great interest.

His first technic was a double investment method in which the wax pattern was covered with investment. At approximately the time of initial set it was submerged in water at 100° F., and 20 minutes later the investment-covered pattern was invested in the usual manner in a ring. This technic required clock-watching and was never very popular with the profession.

The hygroscopic method was never broadly accepted until Hollenback³ described a simplified technic in 1943 which obtained the expansion by completely submerging an invested inlay ring in water at 100° F. This technic was popular and produced excellent results, and when combined with vacuum investing it produced extraordinary smoothness of the gold and excellent precision fits. Some variations of Hollenback's technic have been worked out by others.² It is a simple one and will produce castings equal to those produced by any technic and superior to the majority of them.

Most writers on the subject completely ignore inlay wax as a variable. Not only does it expand or contract with temperature changes, but both a knowledge of its physical properties and a high degree of skill are required to produce a wax pattern reasonably free from stress and strains.

The value of using a submerging water bath at 100° F. is that this procedure recovers most of the wax shrinkage that occurs from the flow point to room temperature. In addition to returning the wax to its original size by expansion, the bath also affords water for the hygroscopic expansion of the investment.

It is quite probable that all dental investments have some hygroscopic expansion, which can be produced by lining the inlay ring with asbestos. Scheu⁶ found that cristobalite investment has as much as 3 per cent hygroscopic expansion; Lyon measured it up to 1.5 per cent. Although this hygroscopic property has not been recognized in

the so called "high heat" technic, it has always been a factor in making satisfactory castings by this method. A specification committee working in cooperation with the Research Council of the American Dental Association is now reviewing the specification for dental casting investments. It is hoped that one will be included for hygroscopic investment which will require manufacturers to measure this type of expansion in each investment and list the value on each package sold.

There are two methods currently in use for utilizing hygroscopic expansion. Each of these methods will be superficially described, and references will be cited so that they may be studied in detail.

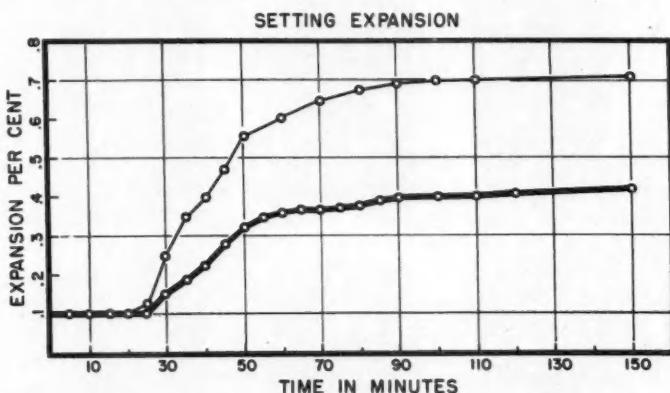


Fig. 3. The lower curve (heavy line) represents normal setting expansion. The upper curve represents hygroscopic expansion caused by submerging in water.

Submerging Water Bath Technic

Method No. 1 is one in which the invested pattern is completely submerged in a water bath at 100° F. The investment used in this technic is Baker's Hygroscopic Investment. Typical curves of normal setting expansion and hygroscopic expansion may be seen in Figure 3. The ratio of water to investment is 19 cc. of water to 50 grams of investment. (It is well to refer here to the research at the National Bureau of Standards, in which it was found that the thicker the mix of investment the greater was the setting and thermal expansion.⁷ This is also true of hygroscopic expansion.) Place the measured amount of water and investment in a clean dry plaster bowl and mix with a hand spatula. After the powder is completely incorporated in the water, vibrate for a short time on a mechanical vibrator to remove as much air as possible, then whip with a mechanical beater for about

75 turns of the handle. If vacuum investing is chosen and a motor-driven beater used, it should be beaten for about 15 seconds.

The inlay ring should be lined with wet asbestos and the pattern thoroughly washed with green soap and dried before investing. It is preferable to fill the ring with investment, then cover the pattern and

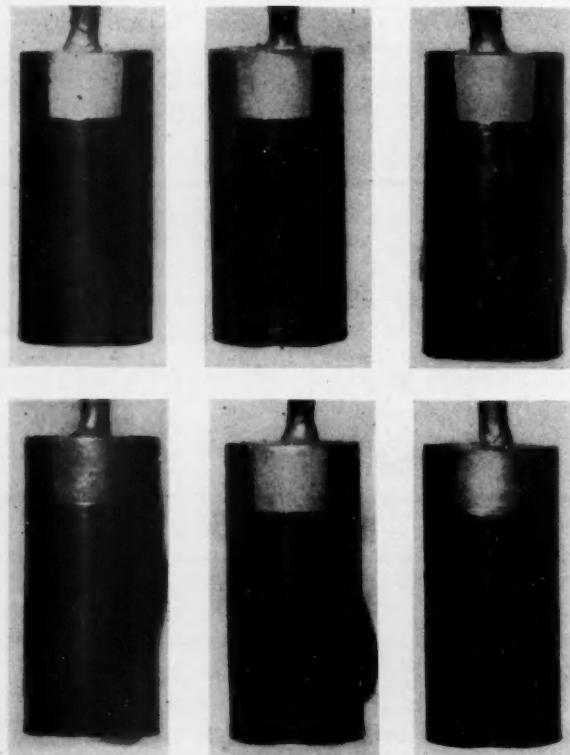


Fig. 4. Six consecutive MOD castings made on a steel die invested hygroscopically by the submerged water bath technic as described in the text.

slowly sink it into the investment, as this reduces the possibility of bubbles on the casting. If the pattern is not invested into the ring then the investment should be allowed to flow down the side of the ring and every effort should be made to avoid trapping of air as the investment flows around the pattern. The investment-covered pattern is then submerged in a 100° F. water bath and allowed to set for a minimum of 30 minutes, after which it can be placed in a pre-heated furnace at 900° F. One hour in the furnace is necessary to complete

the burn-out for the average inlay; larger wax patterns require a longer time in the oven. The value of this technic is that it expands the wax pattern to approximately its volume at the flow point of the wax, which reduces the problem to one of compensating for the casting shrinkage of the gold. The appropriate calculation is as follows: 0.7 per cent hygroscopic expansion plus 0.6 per cent thermal expansion equals 1.3 per cent total expansion; the casting shrinkage of the gold is 1.25 per cent. Figure 4 shows a number of consecutive MOD castings made by this technic.

Research by Suffert and Mahler⁸ at the University of Michigan in 1955 showed that castings made by a technic similar to the one described above produced the most consistent results of any of the four technics they used.

Controlled Water-addition Technic

Method No. 2 is one worked out by Peyton and his associates at the University of Michigan after considerable research in the field of hygroscopic investments and the influence of the various popular technics upon this type of inlay investing. This technic uses the controlled addition of water in varying amounts to influence the desired investment expansion. If this technic is followed in exacting detail it produces excellent castings with a high percentage of reproducibility. To describe this technic it seems desirable to quote verbatim from the authors' own description:¹

"Before using the controlled water-addition technique, it is well to read carefully the manufacturer's instructions accompanying the investment and equipment purchased. However, a general procedure of technique will be presented which is based on the originally designed equipment [Fig. 5].

"After the sprued pattern is mounted on the sprue base [Fig. 6], the flexible ring is placed around it. The investment is mixed and placed into the ring by either hand-mechanical or vacuum investing procedures. If vacuum is used, the supporting metal tubing must be placed around the ring prior to investing but removed immediately afterward. If this metal ring is allowed to remain around the flexible ring, the expansion will be restricted, and proper compensation will not be affected. The flexible ring is then filled, and the level of investment is struck off flush with the top of the ring. The reservoir is placed in position and the required amount of water is added. The exact amount of the water to be added is given in the manufacturer's instructions for the investment being used. After 45 minutes' time, the flexible ring, reservoir, sprue base, and sprue pin are removed, thereby

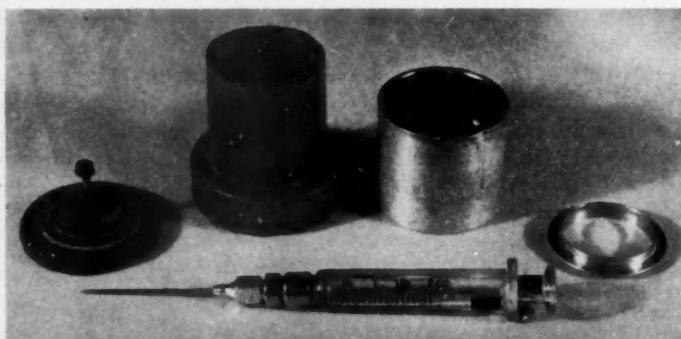


Fig. 5. Original equipment designed for use in the "controlled water added" technic: sprue base, flexible ring, supporting ring, reservoir and syringe. (From Asgars, K., Mahler, D. B., and Peyton, F. A.: J. Pros. Den., 5:711-724, 1955.)



Fig. 6. Manner in which a controlled amount of water is added to the investment immediately after the investing procedure. (From Asgars, K., Mahler, D. B., and Peyton, F. A.: J. Pros. Den., 5:711-724, 1955.)

leaving the cylinder of investment which conformed to the inside of the rubber ring. The wax is then eliminated by placing the investment mold for at least one hour into an oven preheated to 850° F. The use of a rubber syringe and boiling water bath for wax elimination is discouraged when using this technique, since without a surrounding metal ring, excessive flow of hot water through the investment may result in an erosion of the mold cavity and rough castings. A tight-fitting rubber ring placed around the investment cylinder will eliminate this difficulty. However, this procedure is unnecessary if an oven

burnout procedure is used, which has proved itself completely adequate for the job. After the burnout, the casting is then made into the investment cylinder. Since no outside metal ring is used for support, the investments used for this technique must be sufficiently strong to resist the impact of the molten gold as it is thrust into the mold in centrifugal casting procedures. The strengths of both new Ransom & Randolph Hygroscopic Investment and Whip-mix Hygrotrol at the W/P ratios recommended are adequate for this purpose.

"One of the advantages of the water-bath technic results from the usage of water warmed to 100° F. Both setting and hygroscopic expansion can be restricted by wax patterns of the enclosing type, such as the MOD and full crown, whereby the strength of the wax tends to inhibit the expansion of the investment core. The 100° F. water bath softens the pattern during the expansion period, thereby preventing this restriction. This effect is most pronounced in very large patterns having especially heavy occlusal sections, as well as narrowly tapering walls of large dimension; but it is not perceivable in castings of average dental size and shape. The temperature of the bath may also induce warpage in the wax pattern before the investment is set, if the pattern contains excessive strains; this is a possible disadvantage of this technique. If the operator is in favor of this procedure, the flexible ring used in the controlled water-addition technique may be immersed in a 100° F. water bath to allow for this effect. The water level of the bath should, of course, be below the top of the ring to prevent any additional water being supplied to the investment. Since the increased temperature will increase the dimensions of the wax as well, the amount of water added must be reduced. This reduction is about 0.4 c.c., and this value should be checked with the manufacturer's instructions. A dry-air oven may also be used to accomplish the same purpose, but due to its inefficiency in heat transfer in comparison with the water bath, the temperature should be increased to possibly 135° F.

"These procedures have been mentioned since questions concerning them do arise in discussions of modern inlay casting technics. It has been found, however, after making several hundred castings, that the normal cavity preparations confronting the dental practitioner can be quite suitably fitted without the application of heat during the setting process." (See Fig. 7.)

Although the authors of the water-addition technic state that a wax expansion water bath of 100° F. may be used if desired, this seems to produce oversized castings. The technic as advocated is designed to produce enough investment expansion to recover both the shrinkage of the wax and the casting shrinkage of the gold. If the wax shrinkage

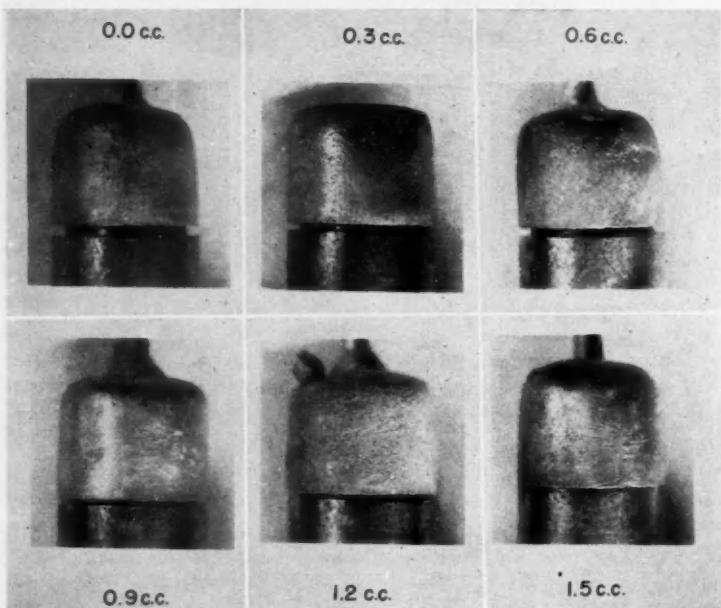


Fig. 7. Effect on casting fit of changing the amount of water added to the casting investment. (From Asgars, K., Mahler, D. B., and Peyton, F. A.: *J. Pros. Den.*, 5:711-724, 1955.)

is recovered in a water bath before the initial set of the instrument, the amount of investment expansion necessary is reduced to the amount needed to compensate for the contraction of the gold, so for this technic it would seem better to eliminate the water bath.

REPRODUCIBILITY OF CASTINGS

Study of the variations between the wax pattern and the subsequent casting was conducted by Suffert and Mahler.⁸ They made 20 castings each—10 occlusal type and 10 full crown type—using four popular casting technics including the one described in this article as method No. 1. The average variation between wax pattern and casting in this technic was 0.1 per cent, which was the smallest of any of the investing methods used and was similar to the figure for the water-addition technic.⁹

Either of the two hygroscopic technics described will produce castings so accurate that the cavity side of the casting should be relieved mechanically or by etching with hydrofluoric acid to provide room for

the cement. Both technics are relatively simple if the reasons for each step are understood.

Auxiliary help can be used to advantage in most offices to invest and cast, so that this scientific process can be kept under the control of the dentist. Inlays and crowns that are produced scientifically require much less chair time in fitting and finishing.

Two outstanding advantages of the hygroscopic technic are (1) the accuracy with which a precision fit may be obtained and (2) the fact that castings made at a lower mold temperature will be smoother than those cast into a high-heat mold, because the lower temperatures



Fig. 8. Two castings made with the same type of gold at different mold temperatures. *A*, MOD inlay cast into a mold at 1700° F. The roughness and porosity of the gold denote large grain structure and contamination of the gold from the disintegrated investment. *B*, MOD inlay cast into a mold at 800° F. The gold is very smooth and closely knit.

produce a smaller denser grain structure which gives the gold greater strength and more resistance to discoloration (Fig. 8).

The casting of an inlay to absolute dimension seems an impossibility for the following reasons: (1) the extreme sensitivity of inlay wax to distortion; (2) the ease with which the setting and hygroscopic expansion of investments are restrained; (3) the variation of the casting shrinkage of the many different casting gold formulas; and (4) the variation in the resistance to expansion of the different shapes and sizes of wax patterns. However, use of either of the methods described here with an understanding of the variables involved and a reasonable skill in minimizing their effects will produce castings of great precision.

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Use of Gold Alloys in Small Castings and Thermal Expansion Techniques

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Regardless of which casting processing technic is utilized, our final objective is the same. We desire a casting that will fit to its preparation with a minimum of internal review and external margination. Furthermore, this adjustment should not require any trauma to the tooth. The casting may require firm finger force for final seating during cementation, but no malleting is necessary for a properly fitting casting. We must also allow for the 20 to 40 microns of cementing medium that is to separate each inner surface from its respective cavity wall. Thus the "standard" to which our technics are directed is simply the "degree of fit." Several different research sources have determined this more specifically, and agree that a summation of errors that exceeds a linear deviation of 0.2 per cent can cause a misfit. This amounts to only 10 microns over a 5 mm. span.

Many dentists have assumed mistakenly that research investigation on our casting technics has been concluded long ago, and that the materials involved have been developed to such perfection that they can be manipulated with considerable latitude of technic. However, current research is still much concerned with accuracy and stability of all elastic impression materials, causes of porosity and surface roughness on castings, mechanisms involved with hygroscopic expansion of investments and many factors involved in the notorious instability of our wax patterns. Such study will persist for some time yet before all elements are understood and we eventually evolve a casting procedure whose accuracy is highly reproducible and trouble free.

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This paper will review the details of the thermal expansion technic, in which the principal agent of expansion is the heated quartz (1.0 per cent) or cristobalite (1.4 per cent) within the investment. Some additional expansion is provided by setting expansion (about 0.3 to 0.4 per cent) of the plaster component and a hygroscopic expansion effect (up to 1.0 per cent) obtained by lining the inlay ring with wet asbestos. These last two modes may not be 100 per cent effective, since they can be restrained by the wax pattern during the plastic stage of the investment. For instance, it has been shown that a softer wax should be used at the stronger shoulders of a full crown pattern shape so these forces of expansion would produce uniform enlargement rather than distortion.¹

THE WAX PATTERN

The wax pattern remains one of our biggest problems. It is impossible to discuss castings adequately without a complete consideration of the wax pattern including how it is formed, the conditions under which it is formed, and all of the subsequent manipulation to which it is subjected. These factors may have definite and profound effects on the size and accuracy of the final casting.

No wax technic is perfect in reproducing cavity details accurately. All possible dimensional changes beyond the control of the operator should be compensated for in subsequent phases of the casting procedure. Abuses to the wax must be recognized and eliminated to minimize dimensional changes, distortions and adaptation failures.

If the wax is melted into the cavity or over the die, as in the indirect technic, much shrinkage occurs unless the material is added in small successive layers. This technic should produce a more uniform pattern with a smaller degree of internal strain.²¹ Molten wax exhibits the greatest degree of linear thermal shrinkage (possibly 0.03 per cent per degree F. above body temperature). Therefore it may be necessary to correct for this shrinkage by remelting deep into marginal areas of patterns being formed on dies and applying pressure until the wax cools. Maintain a slight excess of wax over the marginal area. This method would adapt the wax as closely as possible to the margin with the least error due to shrinkage. Excess wax is then removed with a burnishing action of a warm instrument carried from wax toward margin. Reworking of a wax margin (for a poured or molten pattern) in this manner would reduce shrinkage to a percentage of the 1 or 2 mm. thus corrected rather than to the same percentage of the full length or width of the pattern (or of the molten section involved in the original formation of the pattern). Wax flow curves indicate that

it may be difficult to mold or adapt wax more tightly or accurately into a cavity or die once its temperature drops below 105° F., but the above remarks refer to readapting or correcting small areas by remelting, which involves much higher temperatures.

The more common direct technic of forcing wax into the cavity preparation in operative procedures and maintaining pressure until the wax cools to tooth temperature must certainly induce the worst degree of strain in the wax. Yet the least amount of linear thermal shrinkage occurs with this method. The work of Phillips and Biggs¹⁶

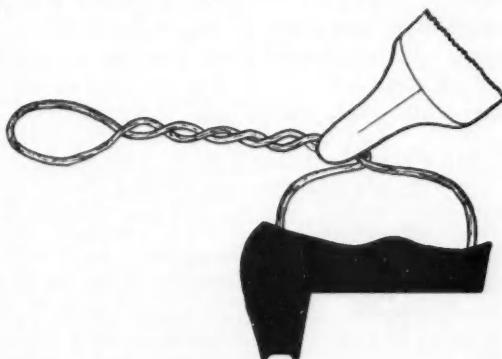


Fig. 1. Wire staple to withdraw wax pattern. Wax will drop from wire ends if heated plier beaks grasp the wire loop.

has shown that internal strains in wax patterns are apparently decreased as the working or forming temperature is increased. Accordingly, it is better to work with the hard waxes at temperatures closer to 130° F. rather than lower, to minimize internal strains.

If any one point with respect to wax patterns is to be emphasized it is that strain release with its resultant dimensional change and warpage can be avoided by immediate investing. It is of extreme significance that in Phillips' work all types of patterns, regardless of whether they were "correctly" handled or abused in formation, could produce accurately fitting castings if invested immediately after being formed.

Pattern Removal

Another critical moment for the wax pattern is during its removal from the tooth or die. If an explorer hook is used, it must be placed in a central position with a slow, careful insertion that will not distort the wax. When the explorer is removed the resultant hole may be repaired easily with a bit of petrolatum. A better method of with-

drawing the pattern is the application of a thin wire staple, which controls movement of the wax more accurately. Once the cavity is cleared, this staple is removed by warming the wire with heated plier beaks (Fig. 1). The pattern will fall away and not bear any holes from the wire ends. A third method has been recommended in which a gold wire staple is used, then invested with the wax. After casting, this staple is simply cut away.

Spruing

Attachment of the proper sprue is a most important step. The point of contact should be the thickest portion of the pattern, usually at the height of proximal contour or at a ridge or cuspal eminence. The proper sprue diameter (see Table 1) is equal to or greater than

TABLE 1. *Sprue Sizes and Their Applications*

BROWN & SHARPE SPRUE GAUGE	APPROXIMATE DIAMETER, MM.	COMMENTS
16	1.3	Thin inlays only; may need reservoir on sprue
14	1.7	Largest size for air pressure casting
12	2.1	Best for most inlays
10	2.6	Use on heavy crowns only

this wax thickness, thus following the principle of providing progressively narrower cross sections of the mold in the direction of the flow of gold. Since this may require a diameter of 2 to 2.5 mm., the danger exists of distorting the pattern by the heat of such a large sprue pin. Use of hollow pins such as needle shafts, or plastic pins with sticky wax, will eliminate this problem.

Too much emphasis has been placed on the "short, thick" sprue. A sprue can be as long as 1 cm. if it is sufficiently thick in diameter. In most inlay rings the length will be limited largely by the need for a minimum of investment thickness (about 6 mm.) behind the mold to resist the force of the casting. The very short sprue has been found inappropriate for vacuum investing techniques in which the investment becomes more dense or less porous.⁹ In such a case less investment should be behind the mold if proper escape of mold air is to occur. Furthermore, it has been shown that the short sprue admits the gold too quickly, resulting in a "subsurface" porosity. This type of porosity occurs just below the entire surface of the casting, including the button.¹⁷

When the pattern is mounted on the sprue base, several details remain to be attended to before the investment is mixed. The sprue base

should be lubricated with petrolatum or soft wax where it contacts the ring so that a better seal is obtained here. The base and sprue are best covered with a film of oil to avoid adhesion to the investment, which can flake or crumble slightly as the sprue is removed.

The Casting Ring

The ring should receive a moistened asbestos liner which serves three purposes: (1) a compressible layer is formed which can yield to the forces of setting and hygroscopic expansion, thus preventing these forces from being directed in upon the pattern excessively, (2) some insulation is provided so that transfer of heat from oven to investment does not occur too rapidly, and (3) it facilitates removal of investment from the ring after casting and quenching is complete. Two layers of asbestos serve no better than one.¹²

Cleaning the Pattern

Finally, the wax pattern should be washed and covered with a detergent. This last step has not been given enough attention in the past, but a pattern which bears cavity debris or blood will result in a casting with a surface roughness capable of preventing its fit. Unless the pattern is taken from a clean, lubricated die, this washing should be a routine operation. Liquid soap or 3 per cent hydrogen peroxide is applied with a brush for this purpose and then rinsed with water at room temperature. After washing, a thin layer of detergent is added to the pattern to reduce surface tension. This is quite effective in aiding flow of the investment over the wax surface and can eliminate very small bubbles which may remain. Allow this detergent to dry before applying the investment, to avoid a water-film effect. The dry detergent becomes effective as soon as it is wetted by the investment mix. Unfortunately, not all detergents are compatible with a particular investment, and the wrong ones can produce a rough surface by retarding the set of the investment, so more than one should be tried for best results.

CRISTOBALITE INVESTMENT

The thermal expansion technic requires the use of an investment which contains cristobalite. This is a refractory formed by heating silica to the high temperature of 2640° F. It became available to the dental profession in 1933.²⁴ Its principal usefulness is the higher percentage (1.2 to 1.4 per cent) of thermal expansion which it provides; it also has the advantages of reaching a high level of expansion at

relatively low temperatures (exceeding 1 per cent at approximately 400° to 500° F.) and of maintaining its maximum expansion through a range of several hundred degrees of temperature, thus being less sensitive to fluctuations or inaccuracy of oven controls. Cristobalite products on the market have been providing ample working time when mixed, but they vary in viscosity and in the surface smoothness of their castings.

Investment Variations for Pattern Types

The dimensional changes characteristic of cristobalite are best suited for the fit of the conventional MOD inlay casting. This technic includes the use of the regular cristobalite investment, which is mixed according to the manufacturer's directions, placed within a ring with one asbestos liner, allowed to set at room temperature (no immersion in water), and heated to 1200° F. Besides the high thermal expansion which is obtained in the oven, several minor expansion phenomena are involved. These are room temperature changes of appreciable amounts, thermogenesis of the setting investment (about 6° to 7° F. by final Gillmore test), normal setting expansion, and a hygroscopic expansion due to the wet asbestos liner.

Satisfactory fit of most two-surface inlay castings is obtained by the above technic, but smaller and thinner shapes and most anterior three-quarter crowns should have less expansion for a good fit. The cristobalite investment can be modified for lower thermal expansion by the addition of a "control powder."¹⁴ For example, a mixture of 70 per cent cristobalite and 30 per cent control powder will yield a thermal expansion at 1200° F. of about 1.0 per cent, and 100 per cent control powder will give only about 0.6 per cent expansion (Fig. 2). Thus cristobalite investment can be adjusted in the composition to give the most suitable fit for the above-listed types of patterns. About 0.1 to 0.2 per cent less expansion can be obtained by heating cristobalite to only 900° F., but no castings should be made into molds at lower temperature because of the risk of producing porosity in the gold. Use of a quartz investment with a thermal expansion of 1.0 or 1.1 per cent at 1200° F. provides a very satisfactory fit for the anterior three-quarter crown.

There remain two more types of patterns for which even the full expansion of 100 per cent cristobalite has been insufficient. These are the average one-surface shape and the full crown shape. Suffert²³ found that 8 out of 10 one-surface castings made into cristobalite were smaller than the die, and 6 out of 10 full crowns were too small across the pulpal wall. The primary reasons for such inadequacy may be

entirely different simply because of the difference in shape. It can be appreciated that the one-surface type allows gold shrinkage to occur with a minimum of inhibition because its mold is small and uncomplicated. On the other hand, a full veneer crown may not be expanded enough because the complete continuity of its lateral walls and its greater bulk offer greater resistance to the forces of setting and hygroscopic expansion.

This dilemma has been overcome by utilization of a wax expansion technic. This is done by placing the freshly filled ring in a water bath

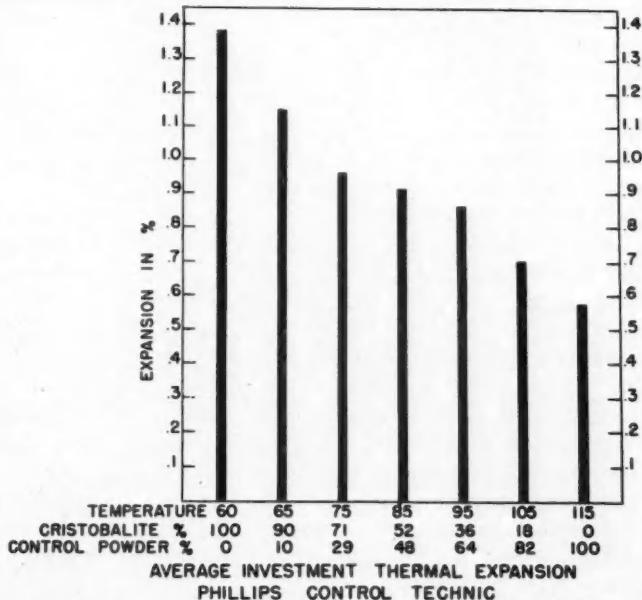


Fig. 2. Thermal expansion of cristobalite and control powder mixtures for room temperatures of 60° to 115° F. for the Phillips control technic.

whose temperature is at 100° F. The material at the center of the ring will reach this temperature in three minutes, thus bringing the wax pattern back to the temperature from which effective shrinkage had occurred in its construction. It should be pointed out that this technic should not allow immersion or any contact of the warm water with the investment. Such contact usually results in crowns that are oversize and fit loosely. Cristobalite investment has considerable ability to expand hygroscopically; its hygroscopic expansion has been measured at more than 1.5 per cent. Such a large expansion factor could also be responsible for distortion of the crown because eccentric thick-

ness and curvatures in different portions of the wax would resist this force in varying degrees.^{10,13} It has been shown that distortions between the shoulder and gingival margins of full crowns become worse with the hygroscopic technic, and such technic fails to expand hard wax at the pulpal wall area.²³

Other Factors Affecting Fit

The varying amounts of expansion recommended above for differently shaped patterns are necessary for thermal expansion technics. Such technics will give the most desirable fit to the cavity when all factors are ideally controlled. It should be understood that surface roughness of the casting can make a significant difference in the fit, thus requiring more or less expansion. For example, a simple, one-surface inlay may be too small or too large, depending on the investment used, even though the amounts of setting and thermal expansion are equal. One investment is coarser than the other.

The need for different amounts of expansion may be due to the characteristic distortions of the pattern which occur as they resist setting and hygroscopic expansion effects of the investment in the early stages of setting.^{12,20} In all investing systems which permit a single technic for all pattern shapes, the setting investment dominates the wax pattern or becomes strong enough to resist crushing by the cooling casting.⁴ This can be accomplished by one of two basic methods: (1) the Granger method of condensing the investment by a vacuum device to accelerate setting and increase strength of the investment,⁸ or (2) the Smyd method²⁰ of using a softer wax and placing the invested pattern in a water bath set at 110° F., which weakens the wax further. In this regard it is significant that most hygroscopic investment technics recommend use of a water bath at 100° F. or more.

Mixing the Investment

Once the type of investment and the appropriate technic have been chosen, the investment should be handled with sensitive and scrupulous care. There is no investment which can produce consistently accurate results when mixed without measurement. Many dentists have concluded that correct water/powder ratio can be judged by consistency of the mix, not realizing that consistency varies with the rate of mixing of these components and the relative humidity of the air. Even those who weigh water and powder most carefully sense an apparent difference in consistency from day to day. If 50 grams of powder is to be used, then the addition of only 1 cc. excess of water

can lower the thermal expansion of the investment by 0.05 per cent. Setting expansion is decreased also. One experiment demonstrated that a difference in fit could be detected clinically when the water was varied by 0.5 cc.¹¹ (This was a molar MOD with extensions into buccal and lingual grooves.) Since such sensitivity has been proven several times,^{6,25} every precaution must be taken. Measuring cups, mixing bowl, and spatula must be clean and dry. If one-half of a small mixing bowl is wet, about 0.5 cc. of water is added thereby. Greater surface



Fig. 3. Vacuum investing apparatus with inlay ring and mixing jar assembled.

roughness on the casting is another consequence which has been observed when certain investments are mixed too thinly. Powder should be weighed to an accuracy of 0.1 gram.¹⁹

The mixing of investment must be thorough for purposes of uniformity and maximum strength, but special attention must also be given to technics which aid in eliminating air bubbles within the mass. Vacuum investing methods can accomplish this most effectively,⁹ especially for those investments that are of thicker consistency. The more popular systems are those in which both spatulation and delivery of investment to the pattern are done under vacuum (Fig. 3). The result is always a denser and stronger material and usually a smoother surface on the casting.¹⁵ Setting time of the investment is not changed. Even without vacuum a mechanical mixer is distinctly better than an ordinary hand spatula technic. Mechanical mixing can be overdone too, affecting setting time and setting expansion. A satisfactory technic

is to rotate the mixer handle 30 turns in each direction at a rate which completes the mixing in 30 to 40 seconds.

Powder and water should both be at 70° to 80° F. Cold tap water during the winter season in the author's area has been as cold as 40° F., which would seriously affect the size of the pattern. High water temperatures accelerate the setting of the investment, and so do waters of high mineral content. Consequently some offices may require storage of distilled water at proper temperatures for mixing with investment.

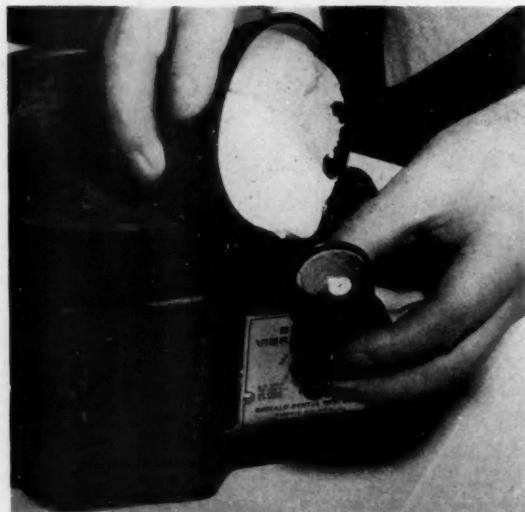


Fig. 4. Vibration of cristobalite investment from mixing bowl into inlay ring.

Applying the Investment

Investment is applied to the prepared pattern in the hand painting method with a sable brush, using a pushing action and an occasional vibration of the sprue with a serrated instrument. Poor coverage or entrapment of air bubbles may be uncovered by blowing away this initial application, then covering the pattern and sprue generously once more with the brush. Sprinkling this mass with powder until saturated has been proposed for additional expansion; however, the authors find results inconsistent and such a technic unnecessary. The low viscosity of cristobalite investment renders it easy to flow into the ring. This is done by placing the bowl on a vibrator which actuates the investment to flow out of the tipped bowl onto the inlay ring, which is held below (Fig. 4). Note that the ring with its enclosed

pattern is not being vibrated in this arrangement. Investigation should be made of the effect of certain heavy vibration practices on the stability of wax patterns.

Most investments set fast enough to give a final Gillmore test (no indentation of a 1 pound weight on a $\frac{1}{24}$ inch wide surface) in 20 to 25 minutes, so that manufacturers recommend that the removal of sprue and initial heating can take place just 30 minutes after finishing investing. Longer setting will do no harm.

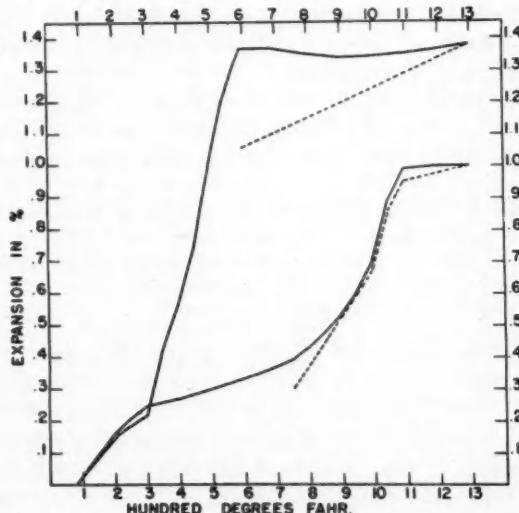


Fig. 5. Heating and cooling curves for a cristobalite and a quartz investment.

The Thermal Phase

The most ideal method of burn-out is to begin with a cold oven. If the oven is already heated, the ring should be placed on top or in front of the oven in such a way as to provide a slow initial warming for 15 or 20 minutes.² Turn the ring several times for even heating. Rapid heating causes boiling of the wax and the generation of a large quantity of water vapor which in turn roughens the surface of the mold. Flakes of investment can loosen from the wall, to appear later as inclusions within the casting or as varied-size pittings in the casting surface.

Another serious effect may occur during rapid initial heating because of a crystalline change that takes place in cristobalite at about 390° F. This results in the most extreme thermal expansion phase dur-

ing the heating of the investment, and a full 1 per cent expansion takes place over the next 200 degrees temperature rise (Fig. 5). In a very hot furnace the outer portion of investment can complete this 200 degree rise before the inner core even begins. The result will be a cracked investment with the appearance of fins or "lace projections" on the gold casting.²

Cracking of investment also occurs in the oven if it has been stored long enough to be dried out. Storage in a humidor or moistening of the investment for a few minutes before placement in the oven prevents the cracking. This illustrates the value of having some excess moisture available to moderate and distribute heat more evenly during the initial heating of the investment.

If the electric controls of a cold furnace are set at high or maximum, the temperature of furnace and investment can be brought to 1200° F. within 20 to 30 minutes (Table 2); however, more time must be al-

TABLE 2. *Heating Characteristics of a Small Inlay Furnace*

TIME ELAPSED	TEMPERATURE IN DEGREES F. WHEN SET TO		
	LOW	MEDIUM	HIGH
10 minutes	325	550	920
20 minutes	450	725	1150
30 minutes	500	850	1300

lowed for a complete burn-out. As wax becomes vaporized (400° to 500° F.) some of it is absorbed by the investment, and it is this portion which requires more time for elimination. If not done, this carbon occludes the porosity of the investment, preventing proper venting of mold air when the gold is cast. Rounded margins are characteristic of a casting made into such a mold. If carbon remains in the investment walls one can see a darkening of the investment around the sprue hole. The casting may be made when this darkening completely disappears and the sprue hole appears red in subdued light. If there is no glowing red appearance in the sprue hole, the temperature has not reached 1200° F. Higher temperatures are not recommended because no appreciable increase in thermal expansion can be obtained and the plaster and salt components of the investment will disintegrate.

A good routine for heating the cold inlay furnace is to obtain a one hour burn-out by switching on the low, medium, and high levels for 20 minutes each. Longer periods may be necessary if bulky crown patterns are involved or if gas furnaces are used in which a less oxidizing atmosphere exists. Once the heating is under way, be prepared to complete the casting, because cooling and reheating will result in a

cracked, weakened investment.²² Furthermore, the amount of thermal expansion can differ on the second heating according to the type of investment used.³

THE CASTING

The investment cools immediately as it is withdrawn from the furnace, sometimes shrinking in the reverse pattern of its expansion curve¹⁸ and sometimes shrinking more severely (Fig. 5). To be assured of all expansion gained in the furnace, the casting should be made within one minute after taking the cylinder from the furnace. This is facilitated by preheating crucible and gold thoroughly with the reducing portion of the blowtorch flame (just beyond the green inner cone) until the alloy is molten. The arrangement of apparatus should allow the operator to hold the flame on the metal with one hand while transferring the cylinder from the furnace to the centrifugal casting machine with the other. Once the alloy is molten, the reducing flame should never leave it, or considerable oxygen will be absorbed. Accordingly, any flux should be provided before the melting starts, not during the process of melting.

Cast as soon as the gold becomes spherical, clear surfaced, light orange, and fluid. Its temperature should be 100° to 150° F. above the upper limit of its melting range.¹⁷ One minute of centrifugal or air pressure force is more than adequate. Quench in water as the button stops glowing. Pickling is done most effectively with 50 per cent hydrochloric acid; however, 50 per cent sulfuric acid is good also and does not corrode metal objects in the laboratory. Either acid will affect only the plaster portion of the investment. Any residue of quartz or cristobalite must be washed from the casting surface or removed by several hours' immersion in hydrofluoric acid. This latter treatment is recommended for all buttons before they are recast.

Henschel¹⁵ has shown retention of acid in casting surfaces that required over four hours of bicarbonate immersion to obtain neutrality. He recommends that after acid treatment the casting should be reheated to a cherry red and then quenched in 70 per cent alcohol. This brightens the casting and dissipates retained acid.

Choice of Casting Alloys

Some dentists are inclined to choose type A golds (Brinell hardness less than 75) for much of their inlay restorations because it is easier to work and draw (proportional limit is low and elongation may exceed 20 per cent), and because it polishes easily to the lustrous, golden appearance given by its high karat (approximately 22 K). These ad-

vantages are of no value, though, when such inlays repeatedly fail to resist functional stresses of the mouth. Many such failures have been witnessed, the inlay usually becoming loose in the cavity within several days to several weeks even though cavity design was excellently prepared. Recognizing this weakness, manufacturers will recommend their type A golds for non-stress-bearing restorations; however these are usually the simple, one-surface type which are known to require more expansion. Unfortunately the high karat, softer golds have greater casting shrinkage.⁷

The choice of golds for dental restorations should be made from types B (Brinell hardness from 70 to 100) and C (from 90 to 140). The difference in casting shrinkage between these two types is not enough to make a significant difference in fit.¹² Ductility of these types is very adequate for burnishing and finishing of the casting, though those alloys which have a Brinell hardness of 120 or more are more susceptible to heat treatment (slow cooling from 840° to 480° F.) which increases hardness and decreases ductility. Alloys cast by the air-pressure method exhibit more ductility than those cast in a centrifugal machine.²

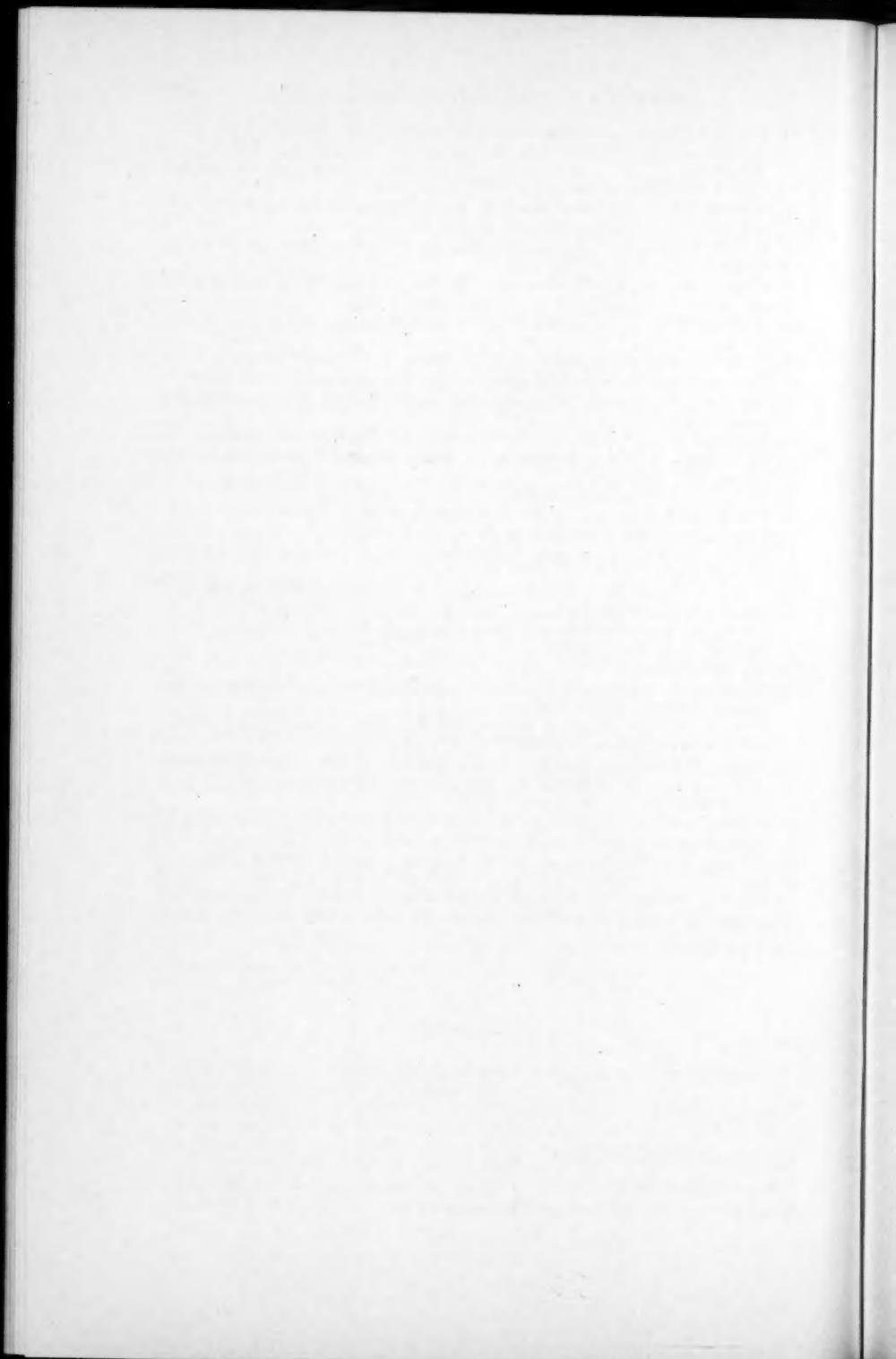
Perhaps a minimum standard for stress-bearing inlays or crowns would require a proportional limit of at least 20,000 pounds per square inch and tensile strength values of at least twice that much. More may be needed as the thickness of stress-bearing areas decreases to less than a millimeter or as the load increases (abutment crowns or inlays for fixed or removable prostheses). It is hoped that future research will define these limits or an acceptable range of values with greater accuracy. All gold manufacturers have charts of the physical properties for each of their alloys. One's choice should be made only after a thorough review of these charts, rather than being based on the cost, color, or popularity alone of a certain alloy. The charts will list the properties when heat-treated or quenched. Choose those alloys which are satisfactory when quenched. Although heat treatment will provide valuable increases in elastic limit, strength, and hardness, few restorations are so treated in the normal dental practice.

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The Veneered Gold Crown

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The veneered gold crown is a full cast restoration which has the labial or buccal surface veneered with either acrylic resin or fused porcelain. The extent of this veneer is governed to a great degree by (1) the position of the tooth to be restored in relation to the adjacent teeth, (2) the occlusion, (3) the esthetic requirements of the individual case, and (4) the amount of reduction possible during the preparation of the tooth.

The esthetic demands made by dental patients, together with structural requirements imposed by good restorative dentistry, have made the veneered gold crown one of the most important restorations employed in the practice of modern dentistry. However, in spite of the widespread use and apparent popularity of this restoration, there exists considerable opposition to its use. This is due for the most part to the use of improper techniques which have resulted in the construction of unsatisfactory restorations.

It is the opinion of the authors that satisfactory crowns and bridges veneered with either acrylic resin or the more recently available porcelain can be constructed, provided the dentist and technician keep in mind certain basic characteristics of the materials involved and employ certain fundamental principles.

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Indications

1. The veneered gold crown may be used as a substitute for the jacket crown, either acrylic or porcelain, when the bite is such that the jacket crown would be broken or abraded in an abnormally short period of time.
2. It may be employed when esthetics demand a jacket crown but the length or shape of the tooth to be restored is such that only a well fitting metal restoration could obtain sufficient retention.
3. The veneered gold crown is indicated in the posterior of the mouth when full crowns are necessary from a restorative standpoint and some degree of esthetics is desirable.
4. Under any circumstances the veneered gold crown can be employed as a bridge retainer when the use of a full crown becomes necessary and good esthetic qualities are required.

ACRYLIC VENEERS**Physical Properties of Acrylic**

The basic physical properties of acrylic are to a major degree responsible for the failure of many operators to obtain satisfactory results when using it as a veneering material, and failure to take these characteristics into consideration has often resulted in inferior restorations.

Acrylic is translucent to varying degrees and while most dentists consider this to be a desirable trait in a tooth-colored restoration, it does permit the esthetics of an acrylic veneered restoration to be influenced considerably by the underlying metal. In some measure this can be prevented by the application of opaquing or masking materials.

Color stability has long been a problem to the manufacturers of acrylic resins. However, most of the materials available today are reasonably color stable; that is, they are color stable if properly manipulated. Most color changes are due either to an improperly constructed restoration or to improper handling of the resin during the veneering process.

Acrylic also exhibits the property of flow, a property which is characterized by the tendency of the material to change its shape permanently when subjected even to relatively light loads over long periods of time. Acrylic undergoes elastic deformation when subjected to intermittent stresses of insufficient magnitude to cause permanent deformation. It is imperative, therefore, that an acrylic veneer be protected from occlusal forces by an adequate thickness of gold. This makes the display of a certain amount of metal necessary in most cases.

Acrylic, of course, does not bond to the metallic portion of the restoration, but must depend on some type of mechanical lock. This inherent weakness, together with the high coefficients of thermal expansion of acrylic as compared to gold, possibly permits a considerable space to form at the interface between the gold and the veneer, even though the veneer may be adequately protected by metal from the forces of occlusion. This space probably allows debris from the oral cavity to penetrate under the veneer. The foreign material itself may discolor or may in some way produce tarnish and corrosion of the underlying metal. Either condition could cause discoloration of the veneer. Proper techniques can minimize the space although it can never be completely eliminated.

Since pure gold is a relatively inert material, gold plating of the area of the crown to be veneered will greatly minimize any chance of tarnish of the underlying metal. This plating may be done by the usual electrical process or by a flash plating process (Caulk's Gold Plating Solution).

Clinical experience has shown that dental patients occasionally abrade acrylic veneers severely during tooth brushing. This problem probably can never be eliminated completely with present resins, but patient education in regard to proper brushing technique, utilizing a relatively soft brush together with a toothpaste that contains no coarse abrasives, should reduce toothbrush abrasion to a minimum.

Tooth Preparation Necessary

Three conditions must be met if a veneered gold crown is to be esthetically acceptable. The restoration must have proper anatomic form and proper color and must display a minimal amount of gold. In order to meet these conditions a definite type of tooth preparation is absolutely necessary.

The authors have found that a preparation having a cervical shoulder on the labial or buccal half of the tooth and a chamfer finishing line on the lingual half is very satisfactory (Fig. 1). In other words, the preparation is that of a jacket crown on the labial and a full gold crown on the lingual. In order to prevent the unnecessary display of gold on the proximal surfaces it is necessary to carry the shoulder into the proximal to a point even with the contact area. This shoulder, at least as wide as the diameter of a No. 557 bur, should end abruptly in a sort of half groove which is parallel to the labial or buccal contour of the prepared teeth. The incisal edge or buccal cusp should be reduced 2 to 2½ mm. in length.

This amount of tooth reduction is absolutely necessary in order to

obtain a minimal thickness of 1 mm. in the veneer and to prevent excessive display of gold. It is important that the shoulder be just as wide at its proximal termination as it is on the labial surface, in order to have the proper thickness of veneering material in that area. Therefore, it becomes quite apparent that this type of preparation can be used only on a tooth that has had some pulpal recession.

Any acceptable method of obtaining the die and working model may be used successfully for constructing this restoration. There are

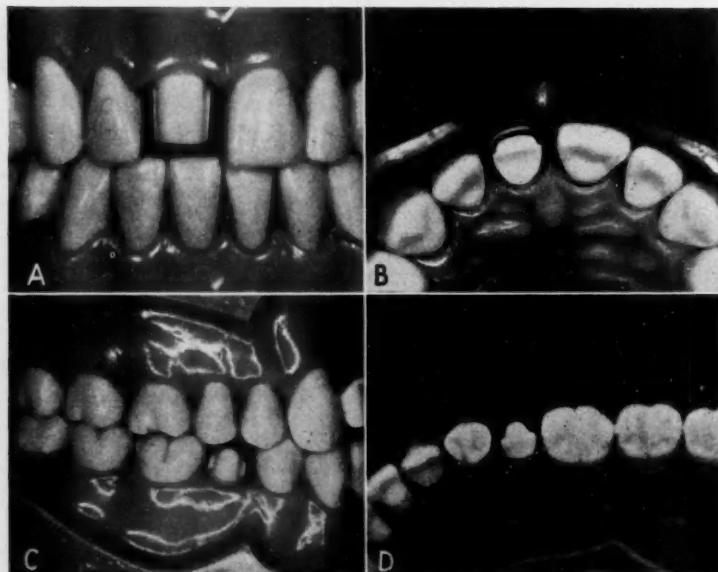


Fig. 1. A, B, Tooth preparation necessary for a veneered gold crown on a maxillary central incisor. C, D, Tooth preparation necessary for a veneered gold crown on a mandibular second bicuspid.

obvious advantages, however, in using the indirect technique and in working with a metal die.

The Wax Pattern

When the wax pattern for the cast portion of the restoration is produced it is absolutely necessary to wax and carve the pattern to complete anatomic form before any attempt is made to remove wax from the area to be veneered. It is difficult, if not impossible, for an operator or technician to visualize and produce correct form or contour when dealing with only a portion of a tooth. Therefore, the restoration is

completed in wax to its final form before reducing the area which is later to be veneered.

When the proper form, contact and occlusion are obtained, the area to be veneered is outlined on the wax pattern with a sharp instrument. Two methods are available for the next step: (1) one may completely remove the wax in the area of the veneer to the labial surface of the die and replace a thin layer by adapting a single layer of 28 gauge sheet wax to the die surface and then seal the sheet wax to the pattern, or (2) one may allow a uniform layer of about $\frac{1}{2}$ mm. to remain in the original wax. The latter method, although more difficult and more time consuming, is to be preferred since carving wax resists deformation during handling more readily than does the softer sheet wax. The peripheral wax around the area to be veneered is not removed occlusally or cervically as far as the gold will be reduced in the finished casting. This excess wax allows molten metal to be fed into the thin portion of the casting from a surrounding area of considerably heavier bulk and assures complete casting in the thin section which backs the veneer. Occasionally it is necessary to run an accessory sprue to this thin area in order to assure a complete casting. However, the proximal outline should be established at this time, since the use of proximal retentive loops makes it impossible to alter the outline in this area after the casting has been made.

Retentive wire loops, 27 or 28 gauge, are then incorporated in the proximal portions of the pattern. These loops can be obtained already formed or they may be formed by the operator from wires of proper size and physical properties. The wire must be non-oxidizing in order to form a good union with the casting, it must be soft enough so that some adjustment can be made after the casting has been completed, and it must have a fusing range high enough to allow gold to be cast to it without changing the physical properties of the wire (for example, Ney's Zephyr wire or Jelenko Pliant wire). These loops are staple-like in shape, about 1 mm. in diameter and $1\frac{1}{2}$ mm. in length. The wire loops are placed from $\frac{1}{3}$ to 1 mm. inside the peripheral margin of the veneer area, perpendicular to the surface of the wax at that point. The loops are warmed very slightly in a flame while being held by tweezers. The wire is forced into the wax only far enough to be securely held. Then a small instrument is heated in the flame so that it is sufficiently hot to melt the wax easily. This instrument is then placed in contact with the wire loop and the loop is teased to its proper position and depth in the wax. If the instrument is sufficiently hot the wire loop will conduct enough heat to melt the wax around the points of the wire, making it a simple matter to guide the loop to place with the heated instrument. At no time should the hot instru-

ment contact the wax. The wire should extend into the pattern about $\frac{1}{2}$ mm., thus producing a loop 1 mm. high and 1 mm. wide (Fig. 2). The number of these loops on each proximal surface will depend on the length of the tooth involved. In most instances two loops can be inserted on each side. Care must be exercised to prevent placing the wire so far incisally on an anterior crown that the wire will show through the acrylic from the relative thinness of the restoration in that area.

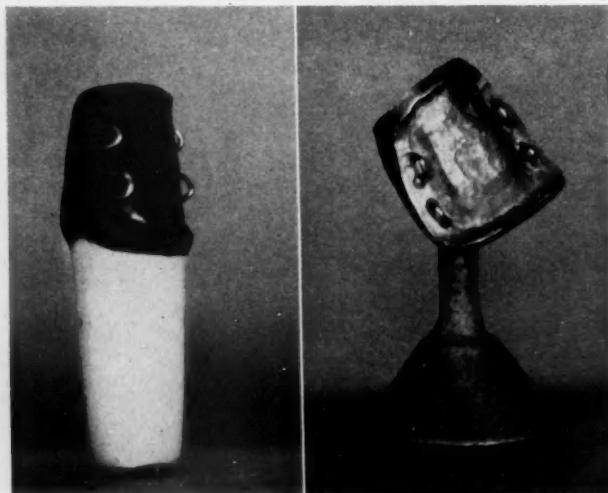


Fig. 2.

Fig. 3.

Fig. 2. Pattern with area to be veneered removed and wire retention loops in place.

Fig. 3. Casting from pattern in Figure 2.

The Casting

Because this restoration has walls that are quite parallel and its inside diameter is relatively small, it is necessary to use an investment which is capable of giving maximum expansion. Any investing and casting technique which is capable of producing this expansion is certainly acceptable. The authors have found that Kerr's Inlay Cristobalite, used with an asbestos liner and a 1300° F. burn-out, is most satisfactory.

After the casting has been produced, the final peripheral outline is established by further reduction of the incisal protection and the cervical collar of gold. This can be accomplished with the use of a No. 557 or 558 steel bur. These areas are undercut in order to augment

the retention afforded by the wire loops and to make certain that there is sufficient bulk of material in these areas to insure proper color in the veneer. This undercutting can be accomplished with a No. 33½ or 34 inverted cone bur, a No. ½ round bur, or a No. 14 wheel bur, taking care that sufficient thickness of metal remains at the occlusal or incisal margin between the opposing teeth and the acrylic veneer. If this restoration is to be soldered to form a bridge or splint, the soldering is done at this time. The entire surface to be veneered should be cleaned and smoothed by going over the surface with a metal bur.

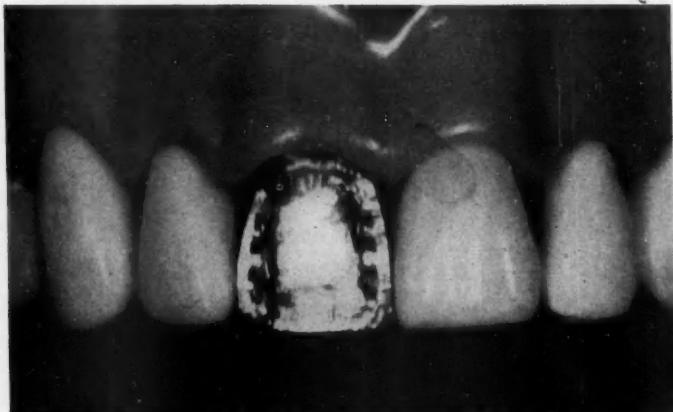


Fig. 4. Casting on prepared tooth with peripheral margin established, surface cleaned with a steel bur and loops bent in toward midline.

In the cases where the tips of the loops appear to be so close to the proposed surface contour of the veneer that they are visible through the acrylic, the loops may be bent toward the midline of the restoration to allow a greater thickness of the veneering material over the wires (Fig. 4). This will not appreciably affect the retentive qualities of the loops, and bending is necessary in the majority of cases. The repositioning of the loops is much more easily accomplished after the casting has been made than when working with the wax pattern. If the veneered area is to be plated, it is done at this time and followed by complete finishing and polishing of the restoration.

Producing the Mold

The completed metal restoration is scrubbed clean and the contour of the veneer is reproduced in tooth-colored wax. Great care should be taken to produce the proper anatomic form and all surface marking in the wax pattern. All of these characteristics will be reproduced

in the finished veneer, and the less finishing and polishing that are required after processing the veneer, the more natural will be the appearance.

The restoration is now invested, labial or buccal surface up, in a small amount of stone, bringing the stone up to but not in contact with the waxed veneer. Care should be taken that no undercuts produced by the contours of the metallic portion of the restoration are left unfilled by stone; such undercuts would cause fracture of the second half of the mold when opened or, even worse, deformation of the restoration. If the restoration is a complicated one, such as a 5 or 6 unit bridge, some of the areas not being veneered may be wrapped in a thin layer of wet asbestos to facilitate subsequent removal from the stone. It is very important, however, that all areas to be veneered be well supported, in the case of crowns, by a hard stone in order to insure adequate resistance to the high pressures to which these areas are subjected during the packing procedures. After this first layer of stone has set completely, it is trimmed to within approximately 2 mm. of the restoration, in all directions, and is then invested in plaster or stone in the bottom half of the flask. This double investing technique enables the technician to remove the bulk of the investing stone without danger of damage to the restoration. When this investment has set, the surface is lubricated with petroleum jelly and the excess is carefully wiped away, taking care that none of the detail of the waxed veneer is obliterated in the process.

The second half of the mold is now poured with well spatulated, bubble-free stone, extreme care being taken to prevent trapping air bubbles near the wax pattern. When the second half is set, the mold is warmed in a water bath to soften the wax just enough to prevent sticking to the second half of the mold. The mold or flask is opened and the second half is examined for imperfections (Fig. 5). If it is satisfactory, the wax is flushed from the mold with a stream of boiling water and all traces of waxy residue are removed with a solvent such as chloroform. When the mold has cooled to room temperature, the case is ready for veneering with acrylic.

Selecting the Veneering Materials

There are many tooth-colored acrylic resins available to the dental profession. The majority of these are satisfactory and any choice is made purely because of personal preference. There are also a number of opaque or masking materials available. Those which are acrylic resins rather than paints or lacquers have proven to be the most successful in the hands of the authors. The paints and lacquers seem to

act as contaminating agents and in some cases appear to actually produce discoloration of the acrylic veneer. The acrylic resin masking material has the added advantage of becoming an integral, inseparable part of the veneer through the process of polymerization. This permits

Fig. 5.

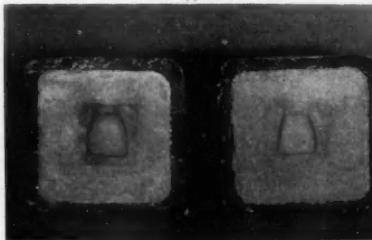


Fig. 6.

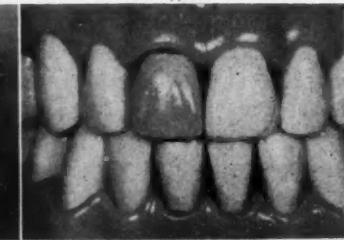


Fig. 7.

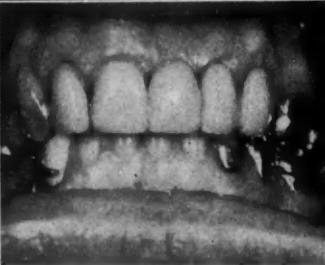


Fig. 8.

Fig. 5. Restoration properly flasked before elimination of wax.

Fig. 6. Finished restoration. In an actual case the gold at the cervical portion would be covered by gingival tissue.

Fig. 7. Proper proximal extension of the acrylic veneer.

Fig. 8. The maxillary right lateral incisor and left cuspid have single acrylic veneered gold crown restorations. The missing maxillary left central incisor is replaced with a fixed bridge having acrylic veneered gold crowns on the adjacent central and lateral incisors as retainers. The pontic also is veneered with acrylic. Because of excessive gingival recession, the gold at the cervical portion was eliminated and acrylic was allowed to contact the shoulders of the prepared teeth in this case. The right mandibular cuspid is restored with a porcelain veneered crown supporting a partial denture clasp.

masking in the retentive areas of the casting without the loss of retention. (However, the autopolymerizing or self-curing resin restorative materials are not suitable as veneering materials. They are very difficult to handle and are not as color stable as heat-cured resins.)

Masking

It is not always necessary to use a masking material. If the thickness of the veneer is sufficiently great its color may not be influenced by

that of the underlying metal. This is particularly true with the darker shades. A veneer no greater than 1 mm. in thickness is probably improved by the use of a masking material.

The material selected should be approximately the same color as the finished veneer. If a close match cannot be made, a darker shade is always better than a lighter one. It is advisable to use separate colors in the masking of the cervical and incisal areas. Blending of two or more powders may be necessary in order that the color of the masking material approaches that of the veneer. The masking materials should be applied in a thin, uniform layer over the area to be veneered. It should never be any thicker than is necessary to obliterate the gold color of the restoration, and special caution should be used to prevent a build-up of material around the peripheral margin of the veneer. As soon as the masking layer is set, the main body of the veneer may be applied.

The Veneer

The resin for the gingival portion of the veneer is prepared first by placing powder of the preselected shade in a small, covered mixing jar. If two or more basic shades of powder are blended, the dry powders should be thoroughly mixed together before the liquid monomer is added. Just enough liquid is added to wet all particles of the powder. The powder and liquid are mixed slightly to obtain uniform color, covered tightly to prevent the loss of liquid through evaporation, and set aside until the mass reaches a doughy consistency.

Gingival acrylic, roughly equal to the bulk of the veneer, is placed over the area to be veneered and adapted to the approximate form with a stainless instrument. A small spatula or cement instrument may be adapted for this purpose. The top half of the mold is placed into proper position with damp cellophane between the two halves and the mold is closed with a bench press. The mold is opened and the veneer is examined for contour and surface detail. A lack of either sufficient bulk of material or adequate flow will make these details appear faint, indicating the necessity for the addition of more acrylic. In that case a small amount of material is added and the flask is again closed in a press. This "trial packing" is repeated until all contours and surface details are registered in the acrylic and the acrylic has a firm consistency. The incisal area is now trimmed with a sharp instrument or scissors in order to remove the bulk that is to be replaced by incisal shade. The remaining gingival material may be shaped by applying light pressure from a flat instrument.

The incisal portion of the powder is now mixed. When all of the

powder particles have been wet by the liquid the material has a sand-like consistency. This incisal material is carried to place with an instrument and patted to proper form. A sheet of damp cellophane is placed over the first half of the flask and the top portion of the flask is positioned and permitted to remain without pressure for a period of approximately 5 minutes. This procedure assures proper blending of the two shades without displacement of the gingival portion. At the end of this time the incisal should have reached a dough-like consistency and should be ready for the application of packing pressure. However, the flask should be opened to check on the shade distribution and to see if more incisal is to be added or excess removed. Necessary corrections are made and the flask is closed with pressure. The flask is opened for a final check, all excess is trimmed from the periphery of the veneer and a new sheet of damp cellophane is inserted between the halves of the flask, and final closure is made.

Processing is done by immersing the flask and press in a water bath at room temperature. The temperature of the water is elevated to boiling over a period of 30 minutes and the water is then boiled for an additional 30 minutes. The press and flask are removed from the boiling water and allowed to bench-cool to room temperature. The flask is opened and the restoration is removed from the investing stone carefully so as not to damage the margins or distort the restoration. If the packing is carefully done and all excess is removed before the final closure of the flask, there will be little additional flash of acrylic at the margins of the veneer. What little flash there is can be removed with a sharp knife or a carefully manipulated fissure bur and these areas can be carefully polished. The cellophane used between the two halves of the flask gives an ideal surface to the veneer, so care should be taken while polishing the marginal areas that this ready-made finish is not disturbed.

The finished restoration should be stored in water until it can be cemented in the patient's mouth. This prevents any dimensional change in the veneer which might occur from the loss of water absorbed during the curing process and the subsequent sorption of water in the mouth.

FUSED PORCELAIN VENEERS

While it is important to recognize that clinically acceptable acrylic veneers can be made, it is foolish to believe that present acrylics approach the ideal as restorative materials. It is quite apparent from the previous discussion of the disadvantages of acrylic resin that acrylic allows considerable latitude for the development and improvement of veneering materials.

For many years, fused porcelain has been recognized as a restorative material with superior esthetic qualities. This characteristic has been responsible for the continued popularity of the material for the construction of the jacket crowns. However, because porcelain is extremely friable and does not produce a mechanically sound restoration under an adverse bite, it obviously cannot be used as the sole material in the construction of a bridge.

It is not surprising that there have been many efforts to combine fused porcelain with metal in order to borrow the mechanical qualities of the cast restoration. Early efforts along these lines could not be considered successful but in the last few years much progress has been made. While there are now a number of porcelain veneering processes available to the dental profession, the clinical experience of the authors has been limited to one process only (Ney Oro Porcelain). This process allows the use of equipment ordinarily found in the dental office. The materials involved are a gold alloy with a melting range of 1880° to 1930° F., a solder with a melting range of 1800° to 1830° F., an opaquaing medium, a porcelain which fuses at 1650° F., and an overglaze fusing at 1600° F. With this combination of materials it is possible to produce a cast restoration which accurately fits the prepared tooth and which is veneered with porcelain showing little or no metal. The veneer forms what is believed to be a chemical bond with the gold, eliminating any necessity for retentive loops or undercuts.

It would not be completely honest to state that the esthetic qualities of an excellent porcelain jacket can always be duplicated, but acceptable esthetic results can be obtained under most circumstances. The primary difficulty is one of consistent color matching, and continued improvements along this line allow a safe prediction that this difficulty will soon be completely overcome.

That these restorations are mechanically sound is a clinically proven fact. In a series of more than one hundred restorations observed over a period of three years, only three restorations exhibited mechanical failure and these were due in two cases to improper tooth preparation and in one case to faulty handling of the veneering material. In the vast majority of these cases there was actual occlusion with some portion of the porcelain veneer. Many of the restorations were crowns constructed to support partial denture clasps and the retentive areas were constructed on the surface of the porcelain veneer.

Tooth Preparation

The preparation of the tooth for this restoration is essentially the same as that for the acrylic veneered crown. Because of the strength

of the materials and the true adhesion of the veneer to the metal it is possible to veneer areas of the tooth that cannot be covered with acrylic. The preparation for the porcelain veneer should be a modification of the previously discussed preparation in which any area that is to be veneered is reduced at least 1 mm. more than it would have been had the tooth been prepared for a full gold crown. This is especially true when an anterior tooth is going to be restored with an unsupported porcelain incisal edge. This can result in a very satisfactory restoration but necessitates the reduction of the incisal edge by about 3 mm. in order to allow sufficient thickness of porcelain plus the underlying metal.

Wax Pattern and Casting

The wax pattern and the casting are produced using most of the procedures outlined for the acrylic veneer. There are two exceptions:

1. It is not necessary to develop any type of retention in the form of loops or undercuts.
2. No effort need be made to form the contact areas, the occluding areas or partial denture undercut areas in gold.

Care must be taken to form a right angle between the surface to be veneered and the surface of the restoration (Fig. 9A, B). In other words, the porcelain always meets the gold in a 90 degree angle at the periphery of the veneer. This is absolutely necessary to provide sufficient strength in this area and to secure proper color in the porcelain. Failure to observe this principle resulted in two of the unsuccessful restorations previously mentioned. In both of these cases there was a thin, sharp layer of porcelain at the incisal edge. This occurred because of insufficient tooth reduction during preparation and resulted in chipping of the porcelain at this point.

Fusing the Veneer

It is impossible to incorporate all of the details of the complicated procedures involved in the fabrication of the porcelain veneer in an article of this length. Most of the basic procedures used in porcelain jacket crown construction may be applied. However, there are certain precautions to take and fundamentals to observe which should prove helpful to those who are experiencing difficulty. Some of these, in proper order, are as follows:

1. The surface to be veneered should be cleaned with a bur and all grease from the fingers should be eliminated with chloroform. The opaquing process is extremely critical since this material forms the

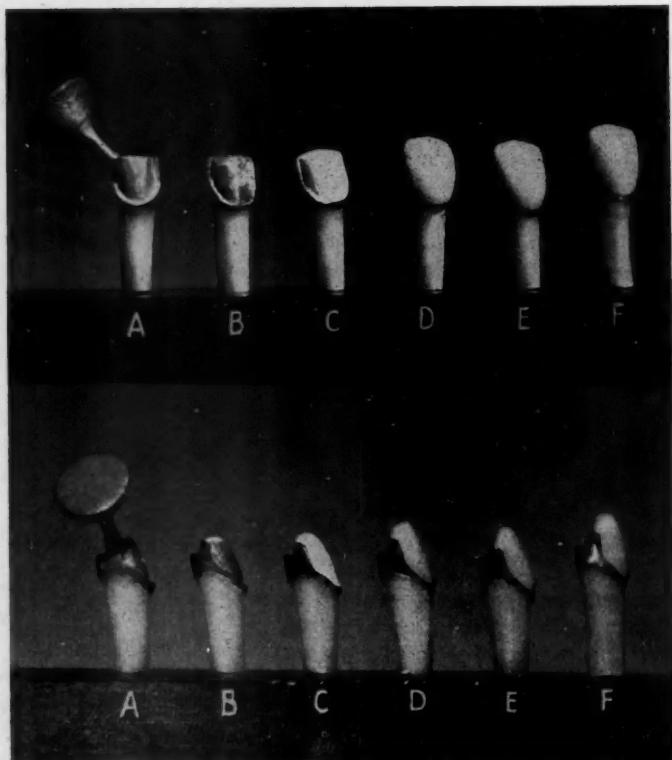


Fig. 9. Steps in producing a porcelain veneered crown. A, Rough casting. B, Casting ready to receive veneer. C, Opaque layer applied. D, veneer fused; notice overcontour. E, Veneer ground to proper form. F, Veneer glazed.

actual bond between the veneer and the gold. (See Fig. 9B.)

2. Opaque material is mixed to a thick creamy consistency. It is applied sufficiently thick to mask out the gold, and is carried just beyond the area to be veneered.

3. A slight bead at the margin may prevent later shrinkage. This is not usually needed after the operator becomes adept.

4. Dry the crown thoroughly, place in the oven at 1100° F., carry to 1450° at the rate of 100° a minute, remove immediately and place under an inverted drinking glass or beaker until cool. Do not cool in the oven since this will cause an overfusing of the material. (See Fig. 9C.)

5. Thoroughly incorporate the basic colors selected for the veneer and mix to a heavy paste with distilled water.

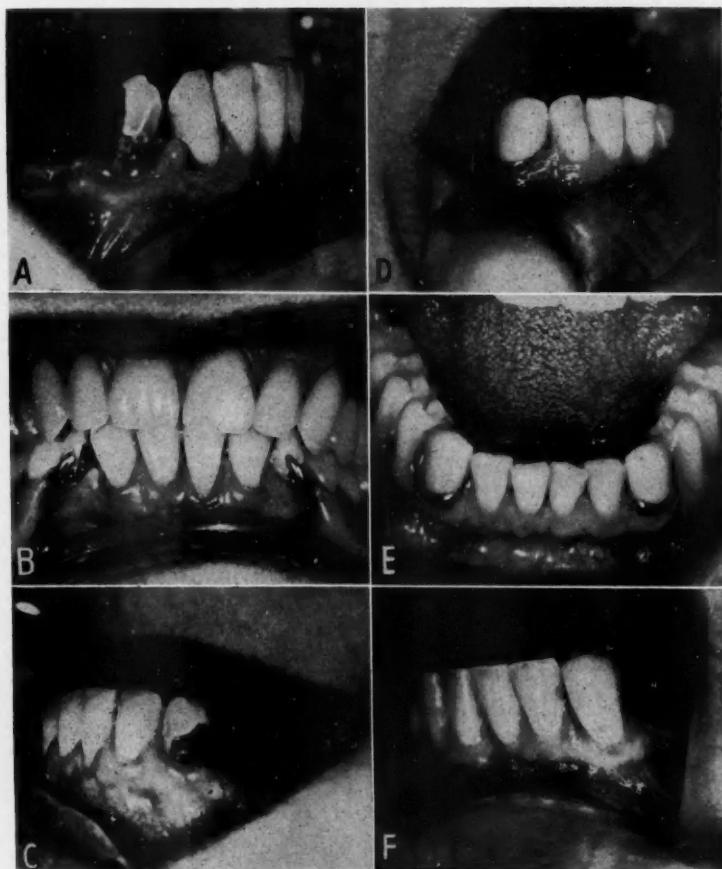


Fig. 10. Case in which carious abutment teeth were saved by endodontic treatment, building the remaining tooth structure to proper prepared form with cast posts and cores, and the construction of porcelain veneered crowns.

6. Apply the porcelain to the crown with brush or instrument, using as little vibration as possible to condense the porcelain. (It has been found that excessive vibration may cause surface roughness in the finished veneer.) Remove excess water by use of gauze, towel or porcelain powder.

7. Keep in mind that fused porcelain shrinks toward its area of greatest bulk. Therefore, if the veneer is properly overcontoured at the periphery, one build-up and bake may be all that is necessary.

8. Dry the crown in front of the furnace, insert at 1100° F., carry

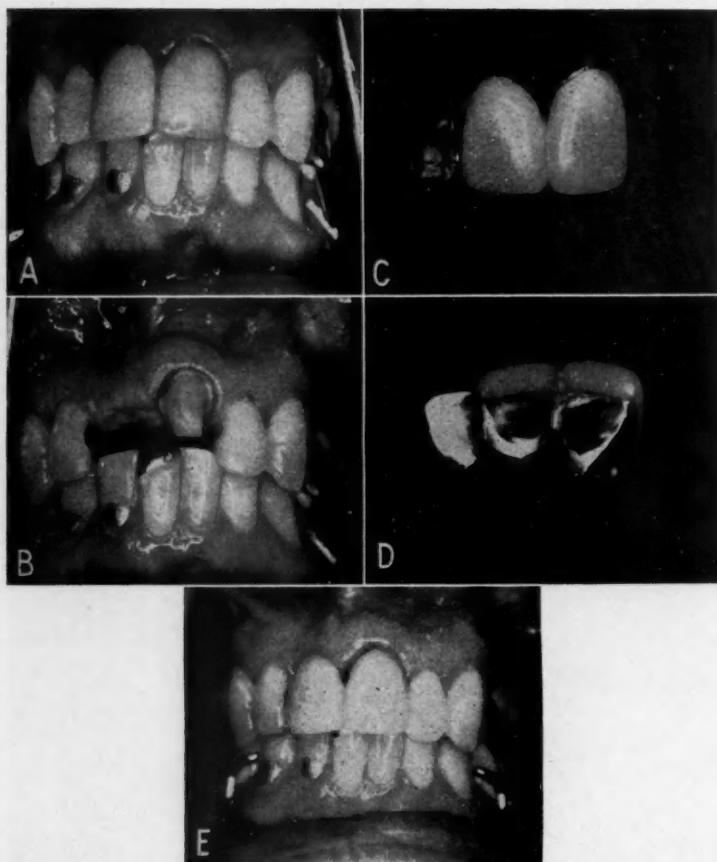


Fig. 11. This patient originally had an all-acrylic cantilever bridge supplying the maxillary right central incisor. This bridge failed for obvious reasons. It was replaced with a bridge having a porcelain veneered gold crown on the left central incisor, a porcelain veneered pontic and a pinledge retainer over a gold foil restoration on the right lateral incisor. The maxillary first bicuspids were also restored with porcelain veneered gold crowns as part of the preparation of the lower arch to receive a class I partial denture.

to 1650° at the rate of 100° per minute and remove as before. (See Fig. 9D.)

9. If necessary, add porcelain to deficient areas and bake as before.
10. Produce proper contour by grinding. (See Fig. 9E.)
11. Be sure that all excess or overlying porcelain is removed where porcelain joins gold. Failure to do so will result in a green line at this point.

12. Smooth with porcelain grinding disks, stones and white rubber wheels.
13. Scrub thoroughly and dry.
14. Rub dry powder into pores of porcelain and bake as before, holding at 1650° F. for a period of 1 to 3 minutes to produce the desired glaze.
15. Pickle by boiling in acid and produce final polish on restoration. (See Fig. 9F.)

The lack of hardness in acrylic and its susceptibility to abrasion do not permit an acrylic veneer to be contacted by a partial denture clasp. A porcelain veneered crown, on the other hand, may be contoured to best support and retain a partial denture with no detrimental effects whatsoever to the veneer. It is this ability to withstand the stresses imposed by partial dentures which earned an immediate and permanent place in modern dentistry for the porcelain veneered gold crown. Probably the time will soon come when the porcelain veneered crown will be the restoration of choice whenever the construction of a veneered crown is necessary.

SUMMARY

Satisfactory acrylic veneered gold crowns can be constructed if a standardized procedure is employed. Success is dependent upon tooth preparation, the form of the wax pattern, the subsequent casting, and the manipulation of the veneering material. Some of the less desirable physical properties of acrylic have served to stimulate research in the field of fused porcelain veneers. While there is still much to be learned about this particular use of porcelain, it is now possible to produce a usable restoration which is mechanically superior to a restoration veneered with acrylic resin.

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Impression Materials in Prosthetic Dentistry

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Any discussion of the impression materials used in prosthetic dentistry must necessarily cover a broad field. It must take into consideration the impression materials used in all of the various fields of prosthetic dentistry, including those used in partial denture construction and those used in crown and bridge prosthodontics. Any discussion of impression materials must also dwell briefly upon the techniques with which they are used, just as any discussion of a specific technique must consider the physical properties and handling characteristics of the impression material involved.

Impression materials used in prosthetic dentistry may be classified as follows: (1) rigid substances, or those which set to a rigid consistency; (2) thermoplastic materials, or those which become plastic at higher temperatures and resume their original form when the temperature has again been lowered; and (3) elastic materials, those which remain in an elastic or flexible state after removal from the mouth.

Rigid materials may be capable of recording tooth and tissue details accurately, but they cannot be removed from the mouth without fracture and reassembly. Thermoplastic materials cannot record accurately minute details because distortion inevitably occurs upon withdrawal from tooth and tissue undercuts. Elastic materials are the only materials which can be withdrawn from tooth and tissue undercuts without permanent deformation, and are therefore the only materials that are suitable for impressions of irregular contours.

Whereas the rigid and thermoplastic materials are used in various combinations in making complete denture impressions, the elastic materials are generally used in the making of impressions for partial dentures, immediate dentures, and for crowns and bridges, where tooth and tissue undercuts and surface detail must be recorded with accuracy.

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A classification of the various types of impression materials may be found below.

Impression Materials Used in Prosthetic Dentistry

RIGID MATERIALS

- Plaster of paris
- Metallic oxide pastes

THERMOPLASTIC MATERIALS

- Modeling plastic
- Impression waxes and resins

ELASTIC MATERIALS

- Reversible hydrocolloid (agar-agar)
- Irreversible hydrocolloid (alginate)
- Mercaptan rubber base materials
(Thiokol)
- Silicone materials
- Thermoplastic elastic materials

RIGID MATERIALS

Plaster of Paris

While all plaster of paris impression materials are handled in approximately the same manner, the setting and flow characteristics of each product will vary. For example, there are a number of pure, fine plaster of paris materials which have only an accelerator added for the purpose of accelerating the set within reasonable working limits.

Each operator usually has a preference for a certain material which suits his own technique best. For a full plaster impression, either in a stock impression tray or some resin tray made from a primary impression, a material is preferred which will set to a hard state, will fracture clean if necessary, and can be reassembled with accuracy. Likewise, those who use a plaster-wash technique in a modeling plastic tray frequently desire to use a pure impression plaster which gives a hard and brittle impression that can be reassembled if fractured.

Other full plaster impression techniques and plaster-wash techniques call for the use of a modified impression plaster in which other binders and plasticizers have been added to permit limited muscle molding while the material is setting. These do not set as hard or fracture as clean as pure plaster of paris, and therefore cannot be reassembled with as much accuracy if fracture occurs. Examples of modified plaster materials are Tru-plastic, Plastogum and Coe-plastic. These are preferred by some operators because of their setting characteristics.

Still another plaster technique calls for the painting of the impression plaster directly onto the tissues, and here a more rigid substance is desired for strength. There are still other operators using full plaster techniques who prefer to use soluble impression plasters. These are

impression plasters which have some substance such as corn starch added so that they will disintegrate when subjected to immersion in boiling water. The use of soluble plasters is limited, but there is sufficient demand for this product that it remains available on the market for those who care to use it.

Plaster of paris impressions are used for complete denture impressions, for labial sections of immediate denture impressions, and for the transfer of copings and crowns in crown and bridge work. Although it was once the only material that could be used for partial denture impressions, elastic materials have completely replaced the impression plasters in this phase of prosthetic dentistry.

Metallic Oxide Pastes

The second category of rigid impression materials is that classified as metallic oxide pastes, these usually being some form of zinc oxide-eugenol combination. A number of these pastes are available today and they are probably more widely used than any other secondary impression material. They may not be used as a primary impression material and are not to be used in stock trays. (In contrast, some of the older operators are still taking acceptable full plaster impressions in modified stock trays. This, however, is becoming a lost art and is no longer taught in dental schools today.)

Metallic oxide pastes are manufactured with a wide variation of consistencies and setting characteristics. For convenience, most of them are dispensed from two tubes, an arrangement which enables the operator to mix the correct proportion from each tube onto a glass or paper mixing slab. The previously prepared tray is loaded and the impression is inserted with or without any attempt at muscle-molding. Generally, muscle-molding of metallic oxide impression pastes is not advisable, as wrinkles will occur if movement is permitted at the time the material reaches its setting state. Therefore, as in most modern impression techniques, the accuracy of the primary impression and of the impression tray has a great influence upon the final impression. Some metallic oxide pastes remain fluid for a longer period of time than others, and some manufacturers claim that muscle-molding is possible. In general, however, all metallic oxide pastes have one thing in common with plaster of paris impression materials; this is that they all have a setting time during which they should not be disturbed and after which no further muscle-molding is effective. In general, it appears that the impression pastes which allow time for muscle-molding record less surface detail than those materials which should be allowed to set undisturbed. It appears that the latter give the best impression

but require greater accuracy and care in the preparation of the impression tray, either through the use of considerable care in the making of the primary impression or in the subsequent correction of the tray periphery by some muscle-molding technique. In either case, the periphery must be nearly accurate before the final paste correction is made. To rely upon the unsupported paste alone to record peripheral detail is an error that has been the cause of many inaccurate impressions and many ill fitting dentures.

One cannot stress too strongly the need for a carefully made primary impression and an accurate tray, properly relieved, before the making of any secondary impression. Although alginate hydrocolloid offers a fast and convenient way of making a primary impression for full denture impressions, its accuracy as a primary impression material can be questioned. Such an impression, made in a stock tray, creates a false peripheral relationship, which results in an impression tray that lacks the peripheral accuracy of a tray made from a carefully made modeling plastic impression.

Although most of the metallic oxide impression pastes are dispensed from tubes in paste form, there are still a few which can be packaged as powder and liquid. In general, these materials are the most accurate of the metallic oxide pastes, and are preferred by many operators because of the accuracy with which they record surface detail. One of these is Ackerman's paste, which is used with a so-called mucostatic technique; this technique stresses accuracy of surface detail, but with less regard for peripheral extension or broad coverage for support. Another such material is the Kydak impression material, which is designed for use with the Kyle impression technique, a highly successful technique in the hands of a meticulous operator.

For the most part, all of the more commonly known metallic oxide impression pastes will give acceptable impressions if used in a tray which fits reasonably well, and if a reasonable amount of care is taken in handling the material.

Although metallic oxide pastes, being rigid substances, are used largely as secondary impression materials for full dentures, they are also used for secondary impressions in partial denture techniques.

There is at least one partial denture technique which calls for the making of a zinc oxide impression of the edentulous ridge in an acrylic or shellac tray. The tray is then finger-loaded through an opening in the perforated tray while an over-all alginate impression is taken of the entire arch. This technique presumably relates the zinc oxide impression of the edentulous ridge to the rest of the arch in a relationship similar to that which will be assumed when an occlusal load is applied.

Metallic oxide pastes are also used as an impression material for denture relining, and may be used successfully if the original denture base is relieved sufficiently to allow the material to flow without displacement of denture or tissues.

THERMOPLASTIC MATERIALS

Modeling Plastic

Modeling plastic is among the oldest of the impression materials used in prosthetic dentistry. Modeling plastic continues to be the material of choice for the making of primary impressions for complete dentures, despite the fact that many manufacturers have encouraged the use of alginate hydrocolloid for the making of primary impressions, and have made impression trays for this purpose. As was stated earlier, the convenience of using alginate hydrocolloid for primary impressions does not necessarily justify its use in preference to modeling plastic for this purpose. The fact remains that it is uncorrectable and requires the support of a stock tray which may cause distortion of peripheral tissues.

Modeling plastic is available in several different colors, each color being an indication of the temperature range at which the material is plastic and workable. A common error in the use of modeling plastic is that it is subjected to higher temperatures than intended by the manufacturer. It then becomes too soft and loses its favorable working characteristics. If a controlled water bath is not used, a thermometer should be used routinely to maintain a temperature within limits that will not cause a weakening of the material or influence its working characteristics. If modeling plastic is softened at a temperature above that intended by the manufacturer, the material becomes brittle and unpredictable. Also, there is the ever-present danger of burning the patient when the temperature used in softening the modeling plastic is too high.

The most commonly used modeling plastic is the red material which, in cake form, softens between 132° and 133° F. and should never be softened at temperatures much above this range. Neither should it, or any other modeling plastic, be immersed in the water bath for an indefinite period of time. Rather, it should not leave the operator's fingers during the softening period. It should be dipped and kneaded until soft, and it should be subjected to no more heat than necessary before inserting the material into the tray and into the mouth. It may then be flamed with an alcohol torch for the purpose of muscle-molding, but should always be dipped back into the water

bath before returning to the mouth, in order to avoid burning the patient. The modeling plastic may then be chilled before removal from the mouth. During sectional flaming and muscle-molding, it should be chilled after each insertion. It may then be trimmed with a sharp knife without danger of fracture or distortion. It is only when modeling plastic is abused that it fails to be an adequate impression material for the making of primary impressions.

The higher fusing black modeling plastic, since it is placed in the mouth at a higher temperature, is more likely to burn the patient and therefore must be handled with greater care in this regard. Since the material is so designed that its flow ceases at a higher temperature, it is used in a tissue-displacement technique, either for the purpose of making a primary impression or as part of the final impression technique. Although full modeling plastic impressions are still being used, they are giving way to more recent concepts of controlled-placement and non-pressure techniques for complete denture impressions. As with the red impression plastic, success in the use of this material depends upon the care with which the operator softens the material. One should remember, however, that a primary impression made with black modeling plastic will give a more extended impression than one made with a lower-fusing modeling plastic.

White modeling plastic softens at about the same temperature as the black material. It was originally used as an orthodontic impression material for the making of orthodontic study and treatment casts. As was stated earlier, it has been largely replaced by the alginate impression materials. However, because it may be used to extend the mucous membrane reflection area beyond normal limits, thereby revealing root and arch formations, it is still used as an impression material for the making of orthodontic study casts. It has no place in prosthetic dentistry, as its temperature range parallels other modeling plastic materials which have become more standardized for prosthetic use.

The gray modeling plastic was designed to be used with a specific technique and was developed primarily for the operator who had never acquired the ability to handle the higher-fusing red compound, thus permitting him to make an acceptable primary impression from which the laboratory could fabricate an acrylic tray for the purpose of making a plaster secondary impression. It offers no particular advantage other than its lower softening range and the fact that it remains fluid in the mouth for a longer period of time.

The red, gray and green modeling plastics are available in stick form, and are used for the purpose of muscle-trimming an impression or an impression tray. The green is available only in stick form, and

is the lowest fusing of the modeling plastics. The red and gray sticks have a higher and broader working range than the corresponding cakes, so that they may be flamed without harming the material. Some operators prefer to use the gray material in stick form for muscle-trimming because of its contrasting lighter color. It would seem that the choice between green and gray compound for this purpose is purely optional and entirely up to the operator. The red impression material is also available in stick form where the operator prefers to use the higher fusing modeling plastic throughout. The operator who has truly mastered the use of red modeling plastic prefers the convenience of using the same material for both the primary impression and the muscle-molding.

Although modeling plastic has been used as an impression material for study casts, it has been entirely replaced by the elastic materials for this purpose. There are still a few operators who prefer to use modeling plastic as a secondary impression material for the recording of edentulous ridges in partial denture construction. When this is done they are using the material with the same philosophy as those who prefer to take a full compound impression for complete dentures. Similarly, modeling plastic can be used as a reline impression material where a full compound impression is acceptable to the operator, although it is generally used only as a means of building up the underside of the denture prior to recording the tissues with some secondary impression material.

Impression Waxes

The second group of thermoplastic impression materials is those impression waxes and resins commonly spoken of as "mouth-temperature waxes." The most familiar of these are the Korecta waxes and the Iowa wax, both of which were developed for specific techniques. One must be cognizant of the characteristics of mouth-temperature waxes and use them knowingly.

The Iowa impression wax, for example, was designed to be used as a wax impression over a modeling plastic correction in an acrylic tray. In this technique, a primary impression is made and an oversized acrylic tray is fabricated which is then corrected in the mouth with modeling plastic until an acceptable correction has been made. It is then relieved in areas of undercut, the periphery is reduced slightly, and the fluid wax is painted onto the surface of the modeling plastic, where in the mouth it becomes a final correction in wax. Although other waxes may be used with this technique, this wax is the one that was developed for the purpose. A modification of this tech-

nique is to establish the final impression in modeling plastic and then cut back only the periphery, which is recorded in mouth-temperature wax. Such an impression, in common with the all-full-wax impressions, causes some displacement of tissues and, therefore, must be considered a modified-pressure technique. Results with either type of impression are excellent, although they are open to criticism by those who feel that a non-pressure or mucostatic record of the tissues for complete dentures is superior.

Like the Iowa wax, the Korecta waxes were also developed for a specific purpose, this being to record the supporting form of the edentulous areas which provide support for a free-end partial denture base. Although four Korecta waxes are available, the No. 4 wax is the most fluid and is quite similar to the Iowa formula in most respects. In fact, the two waxes may be used interchangeably without any detectable difference in results. The No. 1 Korecta wax is not an impression wax, but is instead a supporting wax that is unaffected by mouth temperature. Therefore, it is used as a means of supporting the impression at the periphery during the making of fluid wax impressions. (One may disregard the No. 2 and No. 3 waxes and consider the No. 4 wax as the impression wax and the No. 1 wax as the supporting or base wax.)

The Korecta waxes were developed to be used for the purpose of recording the functional or supporting form of the edentulous ridge for the support of the partial denture base. They may be used either in a secondary impression technique or in a rebasing technique, with the finished denture being rebased to obtain denture support. The mouth-temperature waxes lend themselves well to all rebasing techniques as they will flow sufficiently in the mouth to avoid overdisplacement of tissues. As with any rebasing technique, it is necessary that sufficient relief be provided. In addition, escapement slots or holes in the original base must be used, to avoid locking the impression material against the tissues without opportunity for escape. Given an opportunity to escape, the fluid waxes record the tissues without objectionable distortion, and assure uniformity of support for the denture base.

The difference between wax and modeling plastic is that mouth-temperature waxes have the ability to flow as long as they are in the mouth and thereby equalize pressure and prevent overdisplacement, while with modeling plastic, flow is limited to the amount of flaming and tempering which can be done out of the mouth, and does not continue after the plastic has approached mouth temperature. The principal advantage of mouth-temperature waxes is that they are capable of displacing tissues which are not themselves capable of rendering

support to the denture; however, given sufficient time, there will be a rebound of those tissues which will prevent overdisplacement.

The impression waxes may also be used to correct the periphery of impressions made of more rigid materials, thereby establishing firmer contact at the periphery of the denture. All mouth-temperature wax impressions have the ability to record peripheral detail accurately and at the same time establish better than any other material the correct width of the denture periphery. They have the advantage of being correctible, and if the operator will take sufficient time in the making of the correction, he may record accurately not only surface detail but all peripheral areas that are available for support and retention of the denture.

Another group of mouth-temperature waxes varies considerably in many characteristics from those previously mentioned. These are the Jelenko Adaptol material and the Stalite wax impression material, both of which seem to have a more resinous base. Although classified as mouth-temperature waxes, they are designed primarily for impression techniques which attempt to record the tissues while supporting an occlusal load. In these techniques, the occlusion rim or the denture setup is completed and the occlusion is refined prior to the recording of the final impression. The mouth-temperature wax is then painted onto the tissue side of the denture base and the tissues are recorded while under function, using various muscle movements such as talking, swallowing and sucking. These record accurately the tissues under function, the only question being whether it is better to record the tissues in their resting state, which is the condition they will be in the greater part of the time, or to record their form when a working load is applied. Obviously, the latter is only a relatively small portion of the time that the dentures are being worn.

The more resinous mouth-temperature materials may also be used successfully in the open-mouth techniques. They are not as easy to correct as the fluid waxes, and are somewhat more difficult to handle. All waxes require considerable care in the laboratory. Although the Iowa wax and the Korecta wax can be poured at the convenience of the operator or technician, so long as they are not subjected to temperatures higher than room temperature, the more resinous waxes must be stored at much lower temperatures to avoid flow. Resinous waxes are not ordinarily used in partial denture impression techniques and are limited to specific techniques which are favored by some operators.

Activated resin impression materials, such as the Justi Mucoseal material, are not thermoplastic materials nor are they elastic materials; rather, they are plasticized resins which record only the gross out-

line form of the edentulous ridge without recording surface detail. The Mucoseal material is used with a specific technique that was popular a few years ago and is still used by some operators with success. It is the feeling of those who use this material that it is unnecessary to record the surface detail of the edentulous ridge, since a film of saliva is between the denture and the tissues at all times; therefore, a record of the gross form is all that is needed. This may or may not be true. The fact that such impression techniques have been successful perhaps indicates that an intimate relationship between the denture and the tissues is, in the lower arch, of little importance. It has been shown that retention in the upper arch is directly proportionate to the apposition of the denture to the tissues, but it may be that the film of saliva always present under the lower denture makes close adaptation of the denture to the tissues of little importance and actually nonexistent. One of the most important contributions of Mucoseal impression material and the associated technique to prosthetic dentistry is the recording of sufficient width in the sublingual area to effect a sublingual seal and improve retention of the lower denture. This is not usually accomplished by metallic oxide impressions, which have a tendency to flow to a knife-edge and record falsely the width of the sublingual area.

ELASTIC MATERIALS

Reversible Hydrocolloids

Reversible hydrocolloids, or those hydrocolloids which are fluid at higher temperatures and gel upon a reduction in temperature, are used primarily as impression materials for fixed and removable prosthetic appliances. Although techniques have been devised which utilize plastic tubing for the purpose of cooling the hydrocolloid in the making of full denture impressions, their use has not been widely accepted.

The reversible hydrocolloid impression materials offer few or no advantages over the irreversible, or alginate, hydrocolloid, when used as a partial denture impression material. The latter is sufficiently accurate for partial denture castings.

Irreversible Hydrocolloids

The irreversible hydrocolloids are used routinely in the making of study casts, orthodontic treatment casts and partial denture casts. They are sufficiently accurate for the making of partial denture master

casts when handled properly. As with the reversible hydrocolloid material, the impression must not be stored for any length of time and must be poured immediately. All of the precautions which apply to the handling of the reversible hydrocolloid apply to the alginates as well.

Irreversible hydrocolloid has been used as a correction material for full dentures, but, like the reversible hydrocolloids, its use has not been widely adopted. It has been used as a correction material in modeling plastic impressions and in acrylic trays. Its disadvantages in this regard are, as with the reversible hydrocolloids, that inaccuracies may exist where insufficient thickness of material is present, and that the record of peripheral detail is delicate and easily distorted in pouring the cast. While hydrocolloid may be used satisfactorily as a complete denture impression material, it is questionable whether it offers any advantage over other materials. On the other hand, certain disadvantages are obvious.

Mercaptan Rubber Base Materials

Because of their cost and the need for individual trays in each case, the mercaptan rubber base (Thiokol) materials have not received the degree of acceptance for partial denture impressions that they have for crown and bridge impressions. There is little to be gained through the use of the material for partial denture impressions, as alginate hydrocolloid impressions when properly handled are completely adequate and one may predict that they will continue to be the material of choice.

Not only have the mercaptan base impression materials been used successfully as crown and bridge impression materials, but they are also being used as complete denture impression materials. Many operators report considerable success with their use in this regard. The fact remains, however, that the mercaptan base material is incompatible with moisture, and it remains to be proved just how good a material it is for recording the completely edentulous mouth and whether or not it offers any real advantages over older and time-tested materials. It is convenient to use; the accuracy of the impression tray is not so important as with some other techniques; it has setting characteristics that permit limited muscle-molding; it will withdraw from tissue undercuts, and it is capable of taking an accurate impression. The question remains as to how consistently accurate the material will be for routine use.

Other uses of the mercaptan base impression materials are in the making of stabilized bases for recording jaw relations. In this applica-

tion it enjoys popularity among many operators. Its elasticity offers comfort to the patient during the recording of jaw relations, but how accurately this jaw relation record may be transferred to a rigid cast is open to question.

Silicone Materials

Much that has been said about the mercaptan base materials applies also to silicone impression materials. They offer accuracy and convenience similar to the mercaptan base impression materials, and are being used successfully as crown and bridge impression materials. They are too expensive to use routinely for partial denture impressions. In their present form they are too soft and pliable to be used safely as an impression material for complete dentures, and at the present time they seem to offer little or nothing beyond materials already available for this purpose.

SUMMARY

The impression materials used in prosthetic dentistry are classified as being rigid, thermoplastic or elastic materials. Of the rigid materials, plaster of paris is used as a secondary impression material for plaster wash impressions or for full plaster impressions in modeling plastic, resin, or base shellac trays. The metallic oxide pastes are similarly used as a secondary impression material but almost universally as a full correction rather than as a wash correction. Both of these materials are free flowing and are capable of giving a pressure-free impression.

Other secondary impression materials are the mouth-temperature waxes and the mercaptan base materials. The former is classified as a thermoplastic material and may be used as a full correction material or for correcting or refining the peripheries of the impression. All mouth-temperature waxes continue to flow as long as they are in the mouth, and will equalize tissue loading if given sufficient space and time in which to flow. They displace soft tissues and are used with this fact in mind. Mouth-temperature waxes are used as a secondary impression material in both complete and partial denture impression techniques.

A second, but older, thermoplastic material is modeling plastic, more commonly known as modeling compound. This material is still the preferred material for full denture primary impressions because of the fact that it is correctible and can be muscle-molded. It is rarely used today as a final impression material, because of the fact that it displaces tissue yet does not continue to flow at mouth temperature. Thus, there is no rebound of tissue which has been overdisplaced as with the mouth temperature waxes.

Of the elastic materials, alginate hydrocolloid is used primarily as an impression material for study casts, partial dentures and immediate dentures. It has been misused as a primary impression material for complete dentures owing to the indiscriminate use of ill fitting stock trays which cannot be shaped or trimmed. An impression tray made from an alginate primary can, however, be suitably corrected if the dentist will take the time to do so.

Agar hydrocolloid is not considered as an impression material for complete dentures. It is used primarily in indirect crown, bridge and inlay techniques. Its use for partial denture impressions is not considered to be particularly advantageous over alginate, since results with the latter, when properly handled, are equal to the agar material.

Mercaptan base material is used as a secondary impression material for complete dentures in much the same manner as metallic oxides. It is used also as an immediate denture material because of its elastic nature. It is less fluid, but satisfactory results have been reported. It does seem to record peripheral tissue detail more faithfully, as the setting characteristics permit more muscle-molding than many of the metallic oxide pastes. Like the alginate, its convenience has led to some careless usage, but when used with care it seems capable of recording tissue detail faithfully.

It is too early to evaluate the silicone materials as impression materials for complete dentures. Their use has been limited by their cost, their delicate nature when cured, and the fact that other less costly and less delicate materials are giving satisfactory results.

One may expect to see continued improvements in these newer products which may make them even more suitable as prosthetic impression materials than the materials now in use. They undoubtedly offer much promise as impression materials for immediate and partial dentures because of their greater stability after curing. Improvements in texture and flow may eventually make them adaptable to all prosthetic impression procedures where secondary impressions in individual trays are used.

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The Properties and Manipulation of Mercaptan Base and Silicone Base Impression Materials

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Everything considered, the development of the rubber-like impression materials is possibly one of the most important contributions to dental impression procedure in recent times. It appears that these types of materials can be used with ease for almost any kind of dental impression and with an accuracy not always previously attained. Although the dimensional stability of these materials during storage is somewhat debatable at the present time, they are certainly more stable than any of the other types of so-called elastic impression materials.

CLASSIFICATION

The rubber impression materials now available may be classified as mercaptan base and silicone base, according to their composition.

Many of the products of each general type can be subclassified according to the viscosity of the paste formed and according to their particular specified use.

All of these products include at least a "regular type" which can be used for almost any type of impression. When Sturdevant introduced the use of a syringe for filling multiple cavities in the same manner as with the hydrocolloid technique, a paste of much less viscosity was developed which is generally known as the "syringe type." This type can be injected readily through almost any injection syringe made for this purpose.

It soon became evident that a paste of a higher viscosity than the regular type would be of benefit, and many companies are now manufacturing a "heavy type."

Unfortunately, no specification exists at the present time as to the proper paste viscosities to be used and, as a result, a considerable confusion exists in this respect. Some of the "regular type" pastes are more

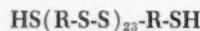
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viscous than are other "heavy types," and some of the "syringe type" pastes are so fluid that they are difficult to retain in the impression tray or in the upper part of the mouth during the impression procedure.

COMPOSITION AND CHEMISTRY OF SETTING

Mercaptan Base Materials

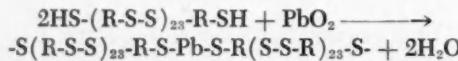
The basic ingredient used in this type of material is known to industry as "Thiokol Polysulfide Rubber." This compound is a polyfunctional mercaptan of the average chemical formula



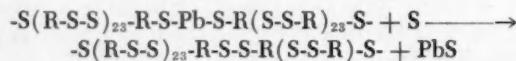
where R is



This polymer, which is a liquid, can be further polymerized to form a rubber-like mass in the presence of a chemical accelerator. Usually both lead peroxide and sulfur are used, and the reactions can be visualized as follows:



Then



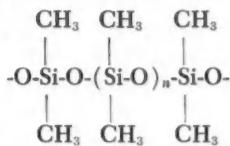
The mercaptan base materials are dispensed to the dentist in two tubes. One tube contains the base material in paste form, and the paste in the other tube contains the chemical accelerators. The paste containing the base is usually white in color, whereas that containing the accelerator is always a brown shade owing to the presence of the lead peroxide.

A chemical analysis⁶ of one of the products manufactured in the United States is presented in Table 1. According to the formula, zinc oxide and calcium sulfate are the fillers for the paste containing the base, and castor oil is the plasticizer for the powdered lead peroxide and sulfur to provide the accelerator paste.

It is not known whether or not the formula presented in Table 1 is typical of all of the commercial products. Very likely, many of them contain a rubber plasticizer and an odor-masking agent commonly used with rubbers.

Silicone Base Materials

So far as is known, the chief ingredient of the silicone base impression materials is polydimethyl siloxane with the structural formula



When it is heated under the proper conditions of temperature and pressure, the dimethyl siloxane can be further polymerized and cross linked by means of a suitable chemical accelerator (e.g., benzoyl

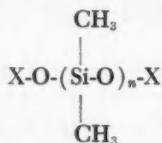
TABLE 1. *Composition of a Rubber Impression Material*

BASE	PER CENT
Polysulfide rubber	79.72
Zinc oxide	4.89
Calcium sulfate	15.39
<hr/>	
ACCELERATOR	
Lead peroxide	77.65
Sulfur	3.52
Castor oil	16.84
Other	1.99

peroxide) to form an elastic, rubber-like material. In this instance, the cross linking is through the methyl (-CH₃) groups and hydrogen is given off.⁴

In all probability, the polymerization reactions which occur in the dental silicones are different than described for the heat-cured variety. However, hydrogen is sometimes evolved in sufficient quantity to cause pitting of the stone cast. This disadvantage has been minimized by the introduction of hydrogen acceptors such as aldehydes or chromium oxide.⁴ The presence of the chromium oxide is indicated by a green color of the paste. Usually the action of the chromium oxide is extended with an aldehyde. In all silicone base impression materials of this type, the presence of an aldehyde of some type can usually be identified by the odor of the accelerator or base of the set product.

It is said that the disadvantage of the hydrogen evolution can also be avoided by the use of a different type of siloxane base such as



where X is the reactive group. An organic tin compound is employed as the accelerator and the cross linkage is obtained through the X groups.³ Although there is a volatilization of certain products of the reaction and probably of some of the silicone gum, the stone surface is not deleteriously affected.

A filler of some type is combined with the dimethyl siloxane to form the paste. The selection and the proper combination of the fillers is most important, since the viscosity and the physical characteristics of the final product are largely determined by this factor. The dimensional stability of the impression appears to be particularly influenced by this consideration.

Most commercial dental products furnish the accelerator as a colored liquid, although one product supplies the accelerator in paste form. It is preferable that the accelerator and the paste be of contrasting colors so that the progress of the mixing to a uniform color can be better observed.

SETTING TIME

The setting or vulcanization time is of importance since the time required should be sufficiently long for the mixing procedure and to permit the seating of the impression, yet the time should not be unduly prolonged to the extent that both the patient and dentist are inconvenienced.

There are two time periods in the setting process which are important. One is the length of time allowable for placing the impression, and the second is the time at which the material is sufficiently vulcanized to remove it from the mouth. The first time period can be called the *working time* and the second the *setting time*.

When a penetrometer test is used consisting of the penetration of a needle 3 mm. in diameter under a load of 200 grams,^{5,8} the working time at room temperature of various products varies between 3 and 9 minutes, with setting times of 6 to 13 minutes. In general, the silicone base materials appear to set faster than do the mercaptan base products. The "syringe type" products seemed to exhibit a longer working

time and setting time than do the "regular type" or "heavy type" materials.

The effect of temperature on the setting properties of the rubber impression materials is quite marked in the case of the mercaptan base materials. With this type of impression material, it is not uncommon to find that the working time is reduced more than 50 per cent between a room temperature of 25° C. (77° F.) and body temperature (37° C. or 98.6° F.). Although an increase in temperature reduces the working time of a silicone base material as well, the effect is not as great as with the mercaptan type.

The setting time of the silicone base impression materials can be controlled by the amount of accelerator employed, but the relation between the accelerator added and the working or setting time is by no means proportional. In general, the retardation obtained by reducing the amount of accelerator is generally more marked than the acceleration obtained by increasing the amount of accelerator beyond a certain limit.¹

The control of the working time of the mercaptan base impression materials by changing the ratio of the accelerator paste to the base paste does not appear to be advisable since the elastic properties of the polymerized product may be adversely affected. If the dentist wishes to accelerate the setting of this type of impression material, it is best to do so by adding a drop of water during mixing. A drop or two of oleic acid will effectively retard the setting when this is desired.

The setting time of these materials is apt to be somewhat difficult for the dental clinician to determine. A lack of tackiness when touched with the finger is not an adequate test.² Possibly the best method for clinical use is to prod the material with a blunt instrument. When no perceptible indentation or deformation is obtained, it can be concluded that the material has set.

MECHANICAL PROPERTIES

The chief attribute of this type of material is that it can be withdrawn over undercuts without appreciable distortion, particularly when hard tissue is present. Any elastic impression material should withstand permanent distortion even though it is withdrawn from interproximal spaces, lingual dovetail preparations, or any similar undercut area normally present in dental restorative procedures.

Possibly the best method to estimate the elastic properties of these products is to compare their properties with the requirements of the American Dental Association Specification No. 11 for Hydrocolloidal Impression Material, so far as is possible. If the elastic properties are

measured after the materials have been subjected to body temperature for 3 minutes beyond their setting time, the properties of the tray materials can be controlled so that they are in the range of the American Dental Association Specification requirements. Insufficient data have been published so far for the "syringe type" materials for final judgment, but according to the results available, this type is somewhat inferior to the "regular type" in its ability to recover after it has been stretched or compressed radically. On this basis, the use of the "syringe type" materials should be confined to the impression of the prepared cavity, and they should always be reinforced with a "tray type" or "heavy type" material for the most accurate results.

The tensile strength, tear strength and compressive strength of most of these materials, particularly the "regular type" and the "heavy type," are comparatively high. In fact, it is virtually impossible to compress many of them sufficiently to cause a fracture. Consequently, there is little danger of a fracture occurring during the removal of an impression made with a rubber material. Unfortunately, such strength is not necessarily an advantage, since it may give the operator a false sense of security. The impression may be considerably distorted during its removal and yet appear to be normal so far as evidence of fracture damage is concerned. From this viewpoint, an impression material which will fracture near its elastic limit is to be preferred.

BIMENSIONAL STABILITY

The dimensional stability of a substance is related to its property to maintain its dimensions accurately over a period of time under normal environmental conditions. It is often claimed that the rubber impression materials exhibit adequate dimensional stability for dental procedures regardless of the length of time of storage.

Certainly, a shrinkage is to be expected for at least two reasons:

1. It is generally recognized that shrinkage always occurs during a polymerization reaction, and the rubber impression materials are no exception to this rule.
2. Whenever volatilization occurs, it is reasonable to assume that in an elastic substance such as rubber, any voids so made will fill subsequently.⁴ As mentioned, gases of various types are evolved during the polymerization of the silicone base materials. According to the equations previously given for the polymerization reaction of the mercaptan base materials, water is one of the products. The loss of the water may well produce a further shrinkage of this material.

There appears to be some dispute as to the magnitude of this shrinkage. The shrinkages obtained with two mercaptan base ma-

terials and two silicone base materials measured while the materials were floating on mercury are presented in Table 2. It is evident that the shrinkage continues for a considerable period after the material has presumably set. No appreciable change in dimension could be observed before 30 minutes after the mixing was begun. As can be noted, the shrinkage of the silicone base materials at the end of 3 days is greater than that of the mercaptan base materials. Undoubtedly, the observed shrinkage can be related to the volatilization of certain ingredients as previously described, as well as to the polymerization reactions.

The clinical significance of the results presented in Table 2 is not entirely clear. As will be discussed later, the impression material must

TABLE 2. *Shrinkage of Rubber Impression Materials*

NO.	MATERIAL BASE	LINEAR DIMENSIONAL CHANGE IN	
		30 MIN. (PER CENT)	3 DAYS (PER CENT)
A	Mercaptan	-0.05	-0.13
B	Mercaptan	-0.03	-0.11
C	Silicone	-0.05	-0.37
D	Silicone	-0.06	-0.87

adhere completely to the tray when the impression is removed from the mouth. Such adhesion is attained either with a perforated tray as is done with the hydrocolloid impression materials, or with an adhesive of some type. Whatever the method of adhesion, the adhesion very likely inhibits the contraction to a considerable extent, perhaps within the allowable tolerance limits. However, the results in Table 2 appear to indicate that the rubber impression materials cannot be said to possess complete dimensional stability, and undoubtedly more accurate results will be assured if the cast or die is constructed within the first 30 to 60 minutes after the impression has been withdrawn from the mouth. Certainly the dimensional stability of these materials is much superior to that of the hydrocolloid impression materials.

ELECTROPLATING

The impression made with either type of rubber impression materials can be electroplated successfully. The use of an alkaline silver plating bath appears to be most satisfactory.⁷ The procedure is essentially the same as for the conventional copper plating technique, except that the plating bath is potassium (or sodium) silver cyanide, and

a silver anode is used instead of copper. The current is limited to 100 to 150 milliamperes.

The areas of the impression to be plated are dusted with a metal powder in the usual manner. Possibly the use of a silver powder is most efficient. In any event a silver "strike" should be present on the surface before the plating begins. Sufficient plating can be obtained overnight.

In general, the silver-plated dies are not quite as accurate as the stone dies constructed within 60 minutes after the impression has been withdrawn from the mouth. The difference is very likely attributable to the lack of dimensional stability of the impression material during the overnight period of plating. The clinician should decide whether or not the loss in accuracy is compensated by the advantages of the electroplated model.

SUGGESTED TECHNIQUE

The clinical details of the technique are set forth in the next article in this symposium. The following basic steps are presented on the basis of the physical and chemical properties of the material as previously described.

Selection of Tray

As previously mentioned, one of the most important considerations for obtaining an accurate impression with the rubber impression materials is the *complete* retention of the impression material in the impression tray. Furthermore, the tray should be sufficiently rigid not to distort with pressure during the operation.

It is important that the tray fit the parts to be impressed reasonably satisfactorily. The thickness of the rubber impression material between the tray and the tissues should be limited to 2 to 4 mm. for best results. For these reasons, the use of a stock perforated tray is apt to be inadvisable.

If an *adequate* adhesive for the rubber impression tray is available, the use of a special tray constructed with cold-cure acrylic resin is preferable. In brief, a preliminary impression of the parts is obtained with alginate impression material or impression compound. A stone cast is constructed in the impression. The involved surface on the cast is overlaid with one or two thicknesses of baseplate wax as a spacer. The acrylic tray is then formed over the wax.

After the acrylic resin has hardened, its "tissue surface" is covered with adhesive, which is allowed to dry.

Proportioning and Mixing

The directions of the manufacturer should be carefully followed in the proportioning of the pastes and accelerators. The setting time of the mercaptan base materials can be regulated by means of the slab temperature, or a drop of water can be added to accelerate the initial polymerization and it can be retarded with the incorporation of a slight amount of oleic acid as previously described. The setting time of the silicone base materials can be controlled according to the amount of accelerator employed.

If a mixing pad is used, it should be glued on at least three sides to prevent scuffing of the paper during mixing. Furthermore, the paper should be of the oil-impervious type, without being impregnated with a substance which might combine with the plasticizers in the paste. There should be no penetration of the paste through the paper while mixing.

The spatula should be of stainless steel or a similar non-corroding or non-tarnishing material. It should be reasonably stiff and preferably tapered similar to an artist's spatula.

When the mercaptan type of material is employed, the brown paste should be spread out first, and both sides of the spatula should be impregnated with it. The white paste can then easily be worked into the brown paste uniformly.

Whatever the material employed, the mixture should be thorough and uniform as judged by the uniform color of the mixture. It should be remembered, however, that a uniform color is not necessarily the sole criterion of judgment in this regard. For example, the dye in a liquid accelerator may spread and diffuse more easily through the paste than the chemical itself. Failure to obtain a uniform mixture is likely the cause of many observed cases of distortion of the impression.

Single Impressions

The use of a 30-gauge copper shell is preferred to the use of the usual copper matrix band. If the latter is used, it should be reinforced with impression compound. The extreme flexibility of the impression material after setting precludes the removal of a soft matrix band from the tooth without distortion.

The matrix shell is selected and trimmed to fit as usual. The inside surface is then covered with an adhesive, which is allowed to dry. The use of a "syringe type" material is indicated in this instance, to be injected with a syringe as described in the next article. It is advisable

to place a drop of the material in an embrasure not included in the area of the impression for future observation.

The matrix band is pressed to place as usual, and held in position until the sample placed in the anterior embrasure resists a permanent deformation with a blunt instrument. Three minutes later the impression can be removed.

Multiple Impressions

Two mixing pads and spatulas are required for this technique. The acrylic tray is prepared for the areas to be impressed as previously described.

Either the "heavy type" or the "regular type" can be used for the tray impression. The material for the tray is mixed first, and the tray is filled and set to one side.

Speed is required for the subsequent technique, especially with the silicone base materials, before the tray material becomes too stiff for use.

The "syringe type" material is mixed and the syringe is filled. The material is injected into each cavity in turn. The base of the cavity should be injected first, and then gradually overfilled. As before, a small bit of material is placed in an embrasure outside the area of the impression for the gauging of the setting time.

It should be emphasized that the tray material should ideally show no signs of stiffening at the time the impression is placed in position. Once the rubber materials begin to stiffen, they exhibit an elastic memory upon withdrawal from the mouth which will result in a distortion.

Edentulous Impressions

The advantage of having three types of materials with different viscosities is particularly evident in the case of edentulous impressions. If the dentist wishes uniform pressure over the entire surface of the ridges and palate, he can employ the "heavy type." If he wishes a minimum pressure, the "syringe type" can be used. A compromise can be effected with the "regular type."

The technique to be employed is very similar to that used with the zinc oxide-eugenol impression pastes, except that it is not advisable to employ a tray compound for the impression tray. The plasticizers in the mercaptan base materials, at least, appear to soften the compound. The acrylic resin tray formed as previously described is preferable.

Usually it will be found necessary to retard the paste for this pro-

cedure by the addition of a fatty acid to the mercaptan base material, or to reduce the accelerator by half when the silicone base materials are used.

The material is mixed as usual and spread over the acrylic resin tray, which has previously been impregnated with the adhesive. From this point, the impression technique is identical with that for the zinc oxide-eugenol impression materials.

General Use

It is evident that the rubber impression materials approximate very closely the long-sought universal impression material. There actually is no type of dental impression for which they cannot be used, although from the standpoint of convenience and economy, they will likely not displace the other types, particularly the use of alginate impression materials for partial denture impressions.

Some dentists are employing the rubber impression materials for use as temporary denture lining materials. A word of caution is apropos in this regard.

Whenever the rubber impression material is to be left in place in the mouth for any length of time, the use of the mercaptan base material is possibly contraindicated because of the amount of lead peroxide employed. So far as is known, the silicone base materials are non-toxic.

The rubber base materials are becoming useful in many branches of dentistry other than operative, crown and bridge and prosthetic dentistry. They are already employed in certain surgical procedures in periodontics, and other uses along similar lines will probably follow.

AN EVALUATION

At the present time, the silicone base materials appear to offer at least two disadvantages which the mercaptan base materials do not possess, namely, a more rapid setting time and less dimensional stability. They also appear to possess a shorter shelf storage time without deterioration than do the mercaptan base materials.

On the other hand, the silicone base materials offer the advantages of cleanliness in handling, less sensitivity to temperature change, and less toxicity when in continuous contact with the tissues as in temporary rebases.

There is every reason to believe that future research and development will result in the elimination of the disadvantages mentioned, and that eventually the silicone base impression materials may replace the mercaptan base materials.

SUMMARY

The presently available rubber impression materials can be classified as mercaptan base and silicone base materials, according to their composition. The sub-classes of each type can be designated as "heavy type," "regular type" and "syringe type" according to their viscosity after mixing and their general specialized uses.

"Thiokol Polysulfide Rubber," a polyfunctional mercaptan, is the chief constituent of the mercaptan base materials. A polymerization to a synthetic rubber is effected by means of lead peroxide and sulfur as accelerators. Both the base and the accelerator are supplied in paste form containing plasticizers and fillers. One of the products of the reaction is water.

The principal ingredient of the silicone rubber impression materials is thought to be polydimethyl siloxane, which is formed into a paste with a carefully compounded filler. The accelerator (an organic tin compound) is usually supplied as a liquid.

Hydrogen and other gases may be evolved during polymerization and may cause pitting of the stone model unless eliminated by a hydrogen acceptor or by the use of a more complex dimethyl siloxane. Volatiles of some nature are always evolved during the vulcanization reactions.

It has been shown that the working time of various products varies between 3 and 9 minutes, and the setting time varies between 6 and 13 minutes; the silicone base materials generally set faster than the mercaptan base materials. An increase in temperature accelerates the setting time, particularly in the case of the mercaptan base impression materials.

The setting time of the silicone base materials can be controlled by the amount of accelerator employed, but the relation is not in direct proportion. The control of the setting time of the mercaptan base materials can be effected by the mixing temperature, or by the addition of a drop of water for acceleration or a small amount of fatty acid for retardation.

The better rubber impression materials may possess elastic properties equal or superior to those of the hydrocolloid impression materials. In general, the strength of these materials is comparatively high.

All of the rubber impression materials shrink after setting; the present silicone base materials tend to shrink more than the mercaptan base materials. Although the materials cannot be considered to be dimensionally stable, in some instances the change may be within the allowed tolerance of error. In all instances they are superior in this respect to the hydrocolloid impression materials.

Rubber impressions can be electroplated successfully with silver. In general, the electroplated die may not be quite as accurate as a stone die constructed within 30 minutes after the removal of the impression from the mouth.

Techniques were suggested for the proper procedures based upon the research findings. The importance of a uniform mix of the base and accelerator was emphasized, as well as the necessity for complete retention of the material in the tray during withdrawal from the parts impressed.

The rubber impression pastes are virtually universal impression materials for any dental procedure.

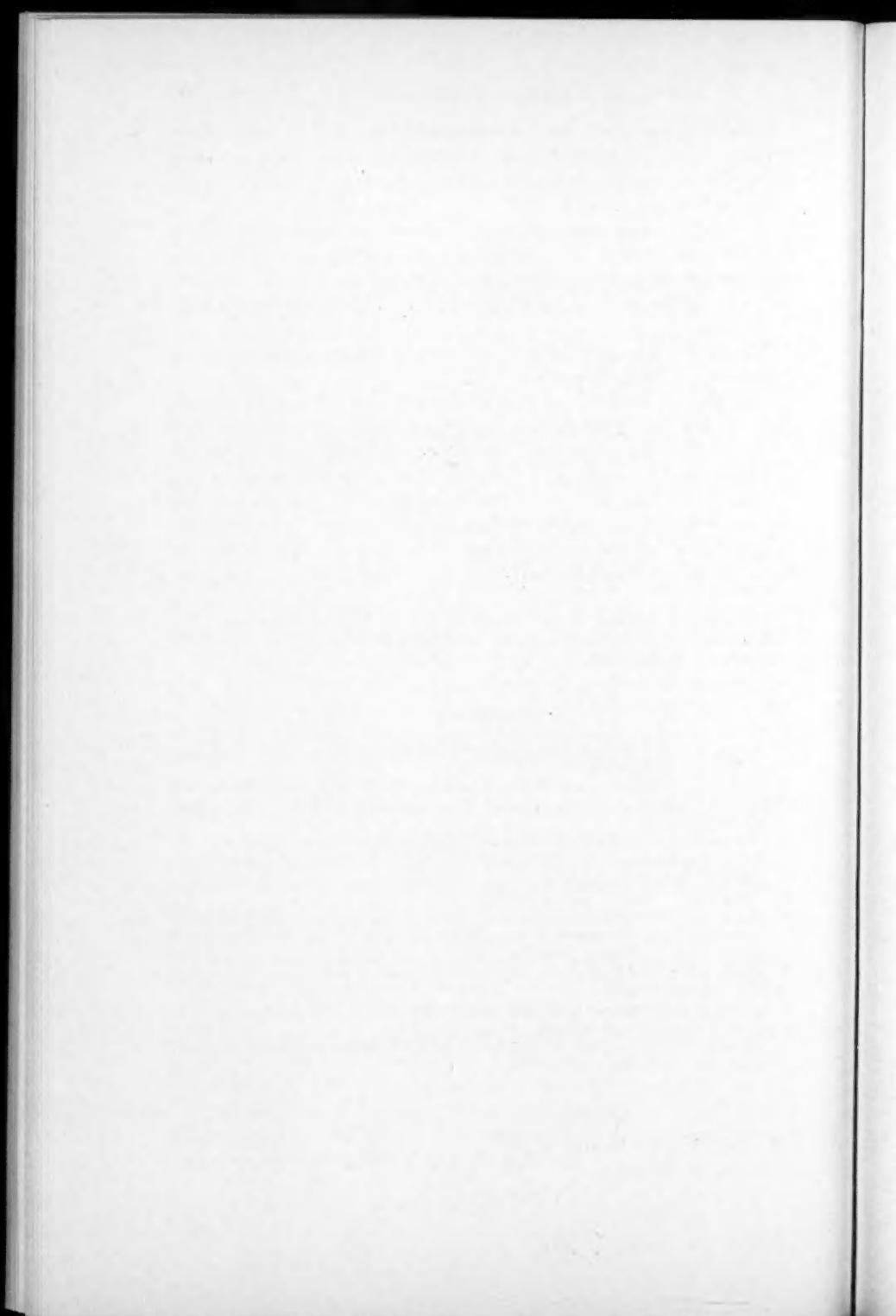
The silicone materials at present generally set too rapidly and exhibit poor dimensional stability in comparison to the mercaptan base materials. On the other hand, the silicone materials present the advantages over the mercaptan materials of cleanliness in handling, less tendency to stain, less sensitivity to temperature change, and less toxicity when in continuous contact with the tissues. Once these important disadvantages are eliminated, it is predicted that the silicone base impression materials will supplant the mercaptan base materials.

The author is indebted to Dr. Eugene J. Molnar, Research Department, Coe Laboratories, Inc., for the information concerning the chemistry of the silicone base impression materials.

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Mercaptan Rubber Impression Technique for Single and Multiple Restorations

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The following techniques for the use of mercaptan rubber (commonly referred to as "rubber base") produce accurate results. Fundamentally, the same techniques also are applicable for the use of the recently marketed silicone impression materials. At present, the silicone material is not the material of choice, but it may be with future improvements.

THE TRAY TECHNIQUE

When undercut areas on the tooth crown just outside the margins are to be recorded in a rubber impression (e.g., impressions for inlays, three-quarter crowns, pin-ledge restorations), a minimum 2 mm. thickness of rubber should be provided, and the container must be rigid. These conditions are best satisfied by using a tray, rather than a tube.

Impression Armamentarium

The special items required are two mixing pads, two spatulas, a syringe, a tray, syringe-type rubber, tray-type rubber (heavy), 8 per cent racemic epinephrine hydrochloride (Orostat), and racemic epinephrine-treated cotton string (Gingi-Pak). (See Fig. 1.) Two types of rubber are used because a double mix technique (using a thicker mix in the tray and a thinner mix in the syringe) reduces the number and size of voids in the impression.¹

The mixing pads must be stiff, large enough in area, and with the sheets attached on all four sides (Coe).

The spatula blades must be stiff (but with some flexibility), polished, wide, long, and with straight side edges which converge to-

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ward the tip. (A modified 10R Buffalo Dental plaster spatula is recommended.)

Preparing the Tray

The tray must be rigid, so it will not flex when filled and pressed to place in the mouth, or permanently bend as the impression is withdrawn. The convenience of stock polystyrene resin trays (Getz) is noteworthy. The "cold-cure" resin tray made over a 2 to 3 mm. wax spacer on the study cast is the preferred tray. (A thickness of rubber



Fig. 1.

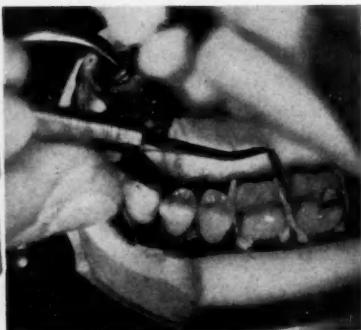


Fig. 2.

Fig. 1. Armamentarium for Sturdevant rubber impression technic.
 Fig. 2. Inserting "Gingi-Pak" string into the gingival crevice.

greater than 3 mm. increases shrinkage and the chance of voids; a thickness less than 2 mm. may cause distortion or tear.)

"Stops" are always desirable, but not essential except for a distal stop in impressions including the distal surface of the last upper molars, to help confine the rubber. These stops should be of cold-cure tray resin, because it is rigid and stable; the use of this material indicates the choice of a resin tray, rather than a metal one. It is *not* recommended to use compound or wax for stops, or for any other purpose (e.g., as a preliminary impression to line the tray), because these materials are not rigid and stable, and compound and rubber are not compatible at their interface.

Peripheral stopping should be provided in the custom cold-cure resin tray at the time of tray construction.

Adequate bonding of the rubber to the tray is accomplished by the application of a rubber adhesive to the tray. Two coats of the adhesive should be applied to the stock polystyrene trays; one somewhat liberal coat is advised for other trays. Though a 10 minute drying period for the adhesive is recommended, this may be shortened by blowing air over the material. There is no disadvantage to applying the adhesive months ahead of the use of the tray.

Preparing the Region

Anesthetize all sensory nerves to the region, apply cotton rolls, and insert the saliva ejector. Anesthesia reduces salivation to facilitate a dry field, and allows widening the gingival crevice without patient discomfort.

Expose the gingival margin by widening the gingival crevice, and arrest gingival hemorrhage and seepage. Cut the double-strand string (as it comes from the Ginci-Pak bottle) slightly longer than the length of the gingival margin. (Where several adjacent teeth are prepared, the string can be long enough to run continuously from one tooth to the next.) Finger-twist the double strand as tightly as possible to produce a dense, slender cord. Now, using the edge of the paddle on suitable "plastic" instruments (Woodson Plastic Instruments No. 2 and 3 are recommended), tuck one end of the cord deep into the crevice about 2 mm. buccal to the point where the buccal margin passes under the free gingiva. Then *progressively* work the remaining length into the crevice, leaving the end of the string exposed to grasp with tweezers later in the technique. (See Fig. 2.)

Occasionally, where the gingival margin is deep, a second double strand should be inserted over the first. Where the marginal gingiva is thin and tight (e.g., labial or buccal), to prevent trauma to this tissue use only tightly twisted, single-strand cord, obtained by separating the double strand material as dispensed from the bottle.

The string will tend to "float" out of the crevice during its insertion if there is slight hemorrhage or seepage, but this can be alleviated by an assistant who repeatedly touches the string with cotton pellets. Then, after the string is well inserted, a drop of 8 per cent racemic epinephrine should be applied via closed tweezer beaks. For extensive hemorrhage in the interproximal tissue, wet a large cotton pellet with 8 per cent epinephrine and pressure-wedge this between the teeth upon the bleeding tissue and leave for a minimum of 5 minutes before removing and inserting the string packing.

For packing aside a large mass of tissue (e.g., distal to the last lower molar), a cotton pack string of larger diameter should be rolled by

the fingers from sterile cotton fibers, then worked into the crevice and wetted via closed tweezer beaks with a drop or two of the 8 per cent epinephrine.

The strings remain in place a minimum of 5 minutes. Where hemorrhage or excessive tissue is present, a minimum of 10 minutes is recommended.

It is suggested that the operator who is inexperienced in this work temporarily withdraw the string packing after 5 minutes and examine

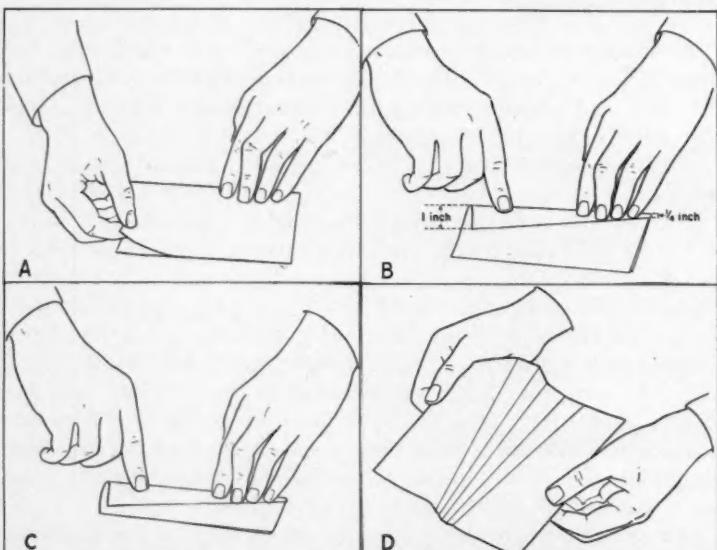


Fig. 3. A, To make a paper funnel, fold in half a sheet from the paper mixing pad. B, Make a second fold with one end $\frac{1}{4}$ inch wide and the other end 1 inch wide. C, Make a third fold by folding over the second fold. D, Unfolded paper.

the region. The soft tissue should be standing away from the tooth, clearly exposing the gingival margin. (This is an excellent time to evaluate the gingival aspect of the cavity preparation, and to make improvements where indicated. Many fine operators do this routinely.) Reinserting the string is easy and rapid.

Apply Microfilm (Kerr) over any cement base, to prevent the rubber from adhering and pulling out the cement.

Making the Paper Funnel

Prepare a funnel, using a sheet from the mixing pad. First, fold the sheet in half (Fig. 3A). Then make a second fold by folding (from the

folded edge created by the first fold) on an angle or bias (Fig. 3B). One end of the second fold should be $\frac{1}{4}$ inch wide, and the other end about 1 inch wide. Then fold again, this third fold having the same measurements as the second (Fig. 3C). Now unfold the sheet of paper (Figs. 3D and 1). It will be used to form a funnel that conveys the mixed fluid rubber into the syringe. (It is suggested that the operator have a supply of prefolded funnel sheets, ready for use.)

Taking the Impression

Place upon one pad the syringe-type material, 2 inches of the white and an equal length of the brown (equal *lengths*, not amounts). Upon the other pad, place the more viscous, tray-type material, 4 inches of the white and 4 inches of the brown (4 inches more or less, depending upon the fit of the tray and the extent of the region to be impressed). (See Fig. 1.)

Assemble a plastic tip on the syringe (Coe) by unscrewing the hub, placing the tip over the end of the barrel, and reapplying the hub. (Align the tip so that its curvature will be in a plane at right angles to the plane through the finger grips of the syringe.) Try the piston in the barrel, adjusting the fit of the washer by turning the screw (clockwise to make a tighter fit). The piston should move in the barrel with about the same finger pressure customarily applied in using an anesthetic syringe. Now, temporarily remove the piston.

Note the time, and begin mixing the tray-type material. First wetting the sides of the spatula blade with the brown material will facilitate mixing. Then pick up the brown material and incorporate it into the white. Frequently interrupt the spatulation to gather the mix with the straight edge of the spatula, lift it, and deposit it on the pad. Thorough incorporation of the base and accelerator pastes is extremely important. A mix free of streaks should be obtained in 1 minute or less.

Gather the mix onto the spatula, convey it into the tray, and temporarily set aside the filled tray. Use care while mixing and transferring the material to minimize the incorporation of air. Filling the tray should not require over 15 seconds.

Now, with the second spatula, mix the 2 inches of brown and white syringe type material on the second pad. This should require approximately 45 seconds.

Immediately transfer this mix via the spatula blade to the center of the unfolded paper funnel (Fig. 4A). Quickly refold the sheet in the same manner in which it was originally folded, and complete the funnel by rolling into a cone (Fig. 4B). Fold over the wide part of the cone to confine the material, insert the small end into the barrel,

and extrude the material by squeezing (Fig. 4C). Not over 1½ minutes should be required to mix the syringe material and charge the syringe.

Temporarily lay aside the syringe. Quickly remove the string packing with serrated tip tweezers (No. 311AX-SSW). The region should be dry, and with all preparation surfaces exposed to view.

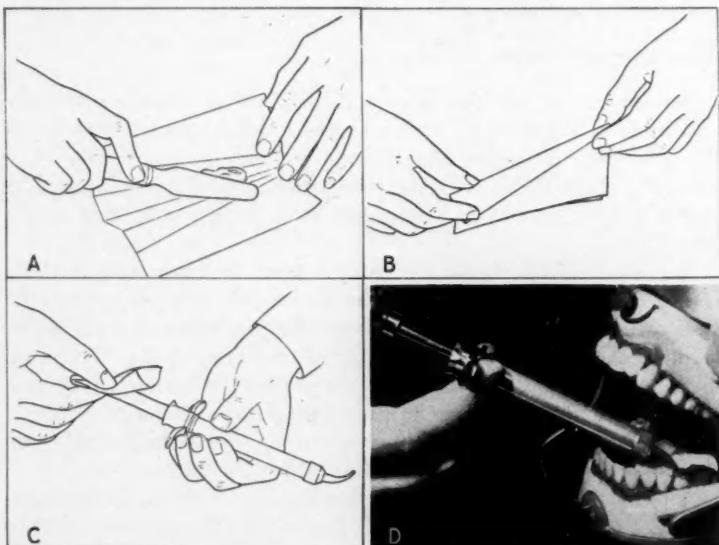


Fig. 4. A, Place the mix of syringe type rubber in the *center* of the unfolded sheet. B, Refold as originally folded, and roll into a cone. C, Insert small end of funnel into barrel, seal off back end by folding, and extrude material by squeezing. D, Remove the string packing, and progressively fill the opened crevices and cavities over and beyond the margins without trapping air. Keep the tip directly upon the gingival and pulpal walls.

Next, deliberately and progressively (moving from distal to mesial) fill the opened gingival crevices and cavity preparations over and beyond the margins, with material from the syringe (Fig. 4D). To prevent trapping air, keep the tip directly upon the gingival and pulpal walls, thereby filling the cavities "from the bottom up," and regulate the movement of the piston so that material will not be extruded too fast ahead of the tip.

After filling and covering the teeth with material from the syringe, immediately remove the cotton rolls and seat the loaded tray over the region. While steadyng the tray in the mouth (do so for the first several minutes), eject some material from the syringe through the

gingival embrasure between and upon two dry posterior teeth not covered by the tray. Allow the moist lip (or cheek) to cover this material, and note when it can recover elastically from an indentation made by a sharp instrument, to determine the setting time of the syringe material. Likewise, test the set of the tray material, wherever it is accessible at the periphery of the tray.

The working and setting times of the rubber material are decreased by an increase in temperature and/or humidity of the room. *Ten minutes from the start of mixing is a recommended curing time*, but it is always best to test for set in the mouth, as described. If the temperature of the room is above 80° F., the working time can be extended by reducing the amount of brown material by a 25 per cent maximum and/or by adding a small drop of retarder solution (provided by one manufacturer in the box of rubber material) to the brown material.

(The technique as given is for Coe's rubber material. If Kerr's material is used, mix the syringe type first and load the syringe before mixing the tray type.)

After the rubber impression is properly cured, remove it from the mouth by a firm pull that is directed as much as possible in line with the draw of the cavity preparation. Usually, the impression will register every detail of the teeth. (Correcting a void by adding a small amount of newly mixed rubber to the impression and reseating it is not recommended.)

The impression should not be stored in any special type of bath or environment. Because the rubber in the impression shrinks a small amount (0.25 per cent, linear, over the first week),² *it is best always to make the model within a few hours*. If the taper of the prepared tooth is minimal, pour the impression immediately; if the taper is maximal (5 to 8 per cent per wall), a day or two delay in pouring is allowable.

Never permit the weight of the impression itself, or of any object, to bear upon the rubber for any length of time, or it will distort owing to flow.

Laboratory Procedure

Two models can be poured from the same impression with accuracy, to provide a split model and a solid model, where both are desired. Make the first model the split one.

Several excellent methods are available for producing a split model. Herewith is presented a strip technique.

Cut stainless steel strips, from material $5/16$ inch wide and 0.002

inch thick, two strips for each tooth to be removable (Figs. 5, 6, and 7). *The teeth to be removable are the prepared teeth with proximal gingival margins and any unprepared teeth adjacent to prepared proximal surfaces.* Each strip, when tentatively held by tweezers exactly over the impression of the proximal gingival outline or margin, should be trimmed to follow, but not quite touch, the buccal, lingual, and gingival contour of the impression. It is emphasized that *the strips do not touch the impression at any place.* Note in Figure 7 how the pairs of strips for each tooth to be removable converge away from the impression. Where a gingival margin is adjacent to an edentulous

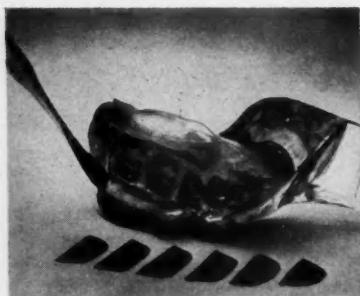


Fig. 5.

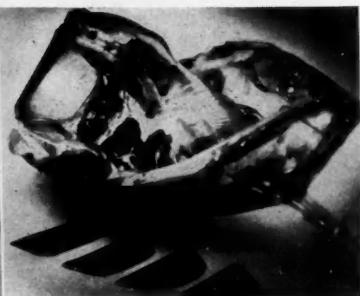


Fig. 6.

Fig. 5. After cutting the stainless steel strips, flow utility wax upon the buccal and lingual regions.

Fig. 6. Each strip is heated and inserted into the wax. The two strips for the second molar die are inserted. Note the clearance of the strip from the impression material.

region, position the strip over the edentulous region, about 1 or 2 mm. away from the impression of the gingival margin. (Note the most distal strip in Fig. 7.)

Tentatively, set aside the strips, in their proper sequence, while a 1 or 2 mm. layer of utility wax is flowed upon the buccal and lingual regions of the impression (Fig. 5). Also, "bead" this wax across the edentulous area (marked X in Fig. 7).

Now take each strip in the tweezers, heat in an open flame, and convey to its proper position (Fig. 6). The strip should be hot enough that its edges will easily and readily enter and move in the wax. If, after inserting the strip, its position is judged to be wrong, convey heat to the strip by warm tweezers, and correct the position while the strip is warm enough to keep the wax soft. Or, the warm strip can be removed, wiped clean of wax while warm, reheated, and then reinserted in better position. NEVER SHOULD PRESSURE BE EX-

ERTED WHILE INSERTING THE STRIPS! Remember, also, that the strip comes close to the impression but never touches it. See that the convergence of each pair of strips is not so great as to bring the outer edges so close to one another that there is inadequate space for the head of the dowel pin.

With a warm spatula and utility wax, seal off any openings between the gingival edges of the *outside* strips and the impression (note Y in Fig. 7).

Pour the spaces between the strips with a 12.5 ml./50 gm. mix of Duroc, a high strength, low setting expansion stone, stopping approxi-

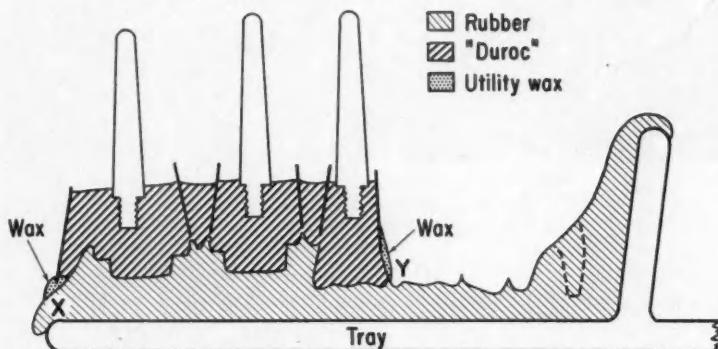


Fig. 7. Anteroposterior section. Note convergence of the pair of strips for each tooth to be removable in finished model.

mately a millimeter short of filling to the top edge of the strips. (Mechanical spatulation and vacuum mixing of the stone are recommended.) While the stone is soft, insert the heads of the dowel pins. Position the pins so they are approximately parallel to the long axis of the teeth and to each other. They will stand without support if upright; this often calls for tilting the impression. Bunching a loose cloth towel under the tilted impression is a convenient method of providing support.

After the Duroc has hardened, apply a separating medium and pour the balance of the model in stone, leaving the ends of the pins extruding a few millimeters to facilitate tapping and pushing them later. Make the model thick enough to provide strength against breakage.

When the model is hard, remove the impression. Then remove the utility wax from the buccal and lingual surfaces of the model. Tap lightly the end of each pin with a small metal hammer until a different "ring" is heard, which indicates that the die has moved slightly from its seating. Next, carefully push the ends of the pins together, causing

the dies to move equally away from their seating. After the dies are removed en masse in this manner, separating them by the fingers is an easy matter. Discard the strips and the V-shaped wedges of stone in between the dies. The dies should have a positive seating in the model (Fig. 8).

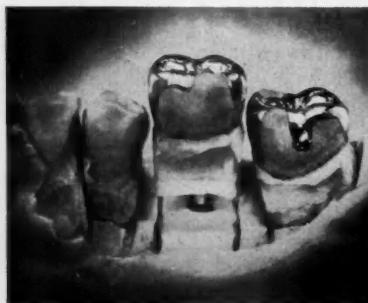


Fig. 8.

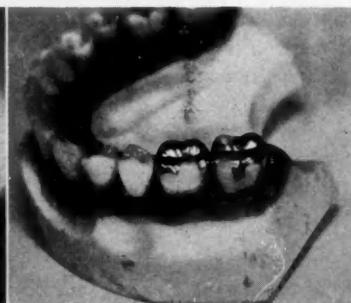


Fig. 9.

Fig. 8. Completed model, with inlays.
Fig. 9. Completed inlays.

CAUTION: A trace of debris upon the closely fitting surfaces of the model will destroy the accuracy which is otherwise possible.

THE TUBE TECHNIQUE

Some operators routinely prepare teeth for complete veneer crowns to marginate above the free gingival crest. Impressions of teeth prepared in this manner offer no challenge using either the tray or the band method. Other operators prepare teeth for crowns which marginate not over 1 mm. subgingivally, and this type of margination is also quite simple to reproduce by way of the tray method, although it does require the prudent use of astringent strings. Further discussion is based upon the premise that a crown should marginate at least 1 mm. into the gingival crevice, and, in many instances, as much as 4 mm. into the crevice, as dictated by carious destruction (Fig. 10). Herewith is described a technique which can be employed to obtain an impression of any tooth prepared to receive a complete veneer crown, regardless of severity of carious ingress.

Perhaps the most important single factor insuring success in this technique is the selection of the proper size copper band. The size of band should be such as to allow for $\frac{1}{2}$ mm. of space between the band and the subgingival margination of the preparation (Fig. 11). Secondly, it must be festooned in such a manner as to extend sub-

gingivally to include all parts of the tooth which have been prepared or ground away. Thirdly, it is necessary to crimp the band in toward the preparation so that the gingival end of the band hugs the prepared tooth snugly at the occlusal or incisal region; then, as it is pushed

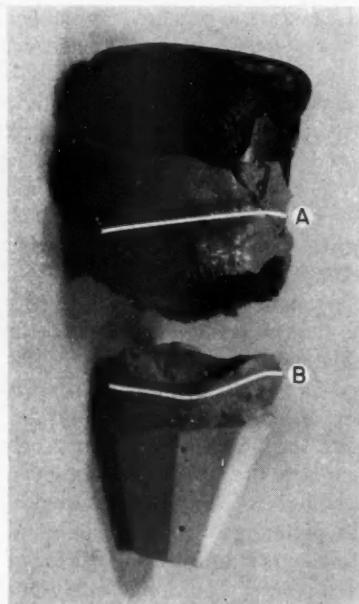


Fig. 10.

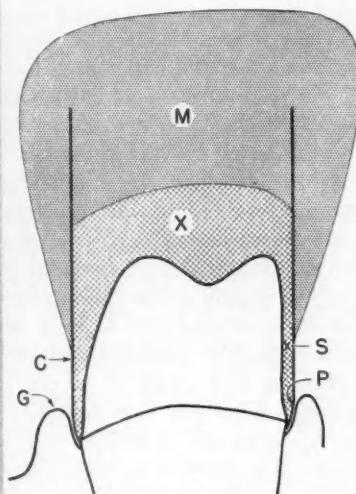


Fig. 11.

Fig. 10. Line A represents the free gingival crest and indicates the distance that the subgingival margination extended into the gingival crevice. The extension in this case was 4.6 mm. Line B represents the subgingival margination as shown on the die; note severe destruction of tooth structure and the chamfer-type margination, which extends 1 mm. beyond the excavated area and a total distance of 4.6 mm. into the gingival crevice.

Fig. 11. M, Modeling compound for closing occlusal or incisal end of band and also for stiffening lateral walls of band. X, Rubber base impression material. G, Free gingival crest. C, Copper band. S, One-half millimeter of space between copper band and prepared tooth. P, Gingival crimp.

gingivally, it can spread, but only enough to accommodate the reception of the prepared tooth. All the while it is being pushed gingivally, the crimped-in portion rides the prepared tooth. In this manner, none of the free gingival tissue is pinched between the band and the prepared tooth. To facilitate the above-described procedures, it is mandatory to use an annealed band, for annealing renders the metal passive and easy to manipulate. After festooning and crimping the gingival

end, the occlusal or incisal end of the band is closed and the lateral walls are stiffened. This can be accomplished with modeling compound or by soldering on an occlusal washer with low-fusing solder. The occlusal or incisal end of the band must be closed to prevent too rapid escape of the rubber base impression material and a subsequent lack of compression of the material against the prepared tooth. *The actual impression taking consumes a small part of the time needed, most of the time being used in properly preparing the band.*

The prepared band is now washed clean, dried thoroughly, and the inside coated with adhesive of the type provided by the manufacturer of the rubber base material being used. A rubber base material of a regular or heavy bodied consistency is selected, the heavier bodied material being favored. Do not use the thin, slow-setting rubber which has been developed for use in a syringe. The mix is made following manufacturer's directions, and the band is filled without delay and carried immediately to place on the prepared tooth, the operator being certain to exert enough force to push the end of the band beyond the gingival margin of the preparation. The tooth need not be dry for this operation, it need only to be washed free of all debris. The band is held in position with light finger pressure, to minimize possible distortion by lips, cheek, or tongue, until set, which occurs in approximately 3 minutes. (Testing in the mouth by the indentation test given in the previously described tray technique is always the safest procedure.) Removal is accomplished by pulling gently with thumb and forefinger, allowing the impression to come off in the line of draw of the preparation. The impression is washed and dried immediately; for best results it should be poured or plated within 2 hours. Delays in pouring the dies are less critical in the band method, however, than in the tray method, because less bulk of rubber is used.

SUMMARY

The mercaptan rubber should be used for the impression when making indirect single and multiple tooth restorations. For the impression of the full crown preparation, the use of a tube is often the method of choice, but the tray technique is advocated for other types of preparations.

Accurate results can be expected if the basic properties of the materials used are understood and correlated with practical application. Rigidity, stability, and a rubber adhesive must be provided in the tray or tube. When the tray method is used, a uniform 2 or 3 mm. thickness of rubber is recommended; also, a double mix technique utilizing a syringe is advised, and the surfaces to be impressed should be ex-

posed to view and dry. Mixing of the base and accelerator pastes must be thorough. Care must be exercised to allow for the development of sufficient elastic property before withdrawing the impression. The impression should be poured as soon as practicable, preferably within a few hours, but if the taper of the preparation is not minimal, a day or two delay is allowable.

Two pours are permitted in the tray impression, and any one of several methods may be employed to make the first pour a split model, where desired. A strip method is recommended.

The author wishes to express appreciation to Dr. Monte G. Miska, Professor of Crown and Bridge, University of North Carolina School of Dentistry, for his valuable assistance on the portion of this article that deals with the tube technique.

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Reversible and Irreversible Hydrocolloid Impression Materials

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Although great accuracy is obtained in the construction of inlays, crowns and bridges by the use of the direct method at the chair, the resulting fatigue and time consumed on the part of both the dentist and the patient resulted in a search for a method which would enable the dentist to reduce his chair time and the number of patient appointments and to delegate most of the laboratory work to the technician. The development of the indirect method passed through several stages. The technics employing modeling compound, Dietrich's impression material and similar products gradually led to the development of elastic impression materials and technics which are at present being used extensively by the dental profession. The materials most generally used today are (1) the reversible hydrocolloids of the agar-agar type and (2) the irreversible hydrocolloids of the alginate type.

Many writers credit A. W. Sears as the originator of the technic which employs a hydrocolloid for inlays and fixed bridges and which he published in the *Dental Digest* in May 1937. A review of the literature discloses that in the July 1933 issue of the *Illinois State Dental Society Journal* an illustrated article was published entitled "A New Method for Fixed Bridge Construction in Two Sittings." In this article by F. van Minden, a method is described "which has been originated and developed in its entirety by Dr. Harry Spiro of Chicago, to whom all the credit for this great advancement should be given."

In November 1933 in a magazine called *The Dental Craftsman* we find five illustrations showing the use of the elastic impression material of the reversible type, also the syringe in which the material was liquefied by heating in boiling water.

This historical background is given to indicate that sometimes it takes a quarter of a century to develop a technic from its first appli-

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cation to its present degree of scientific technic and dependable materials.

That the indirect technic is being accepted more and more in the reconstructive phases of dentistry is due primarily to the development of materials which can accurately reproduce all areas and types of preparations which retain their dimensional accuracy upon removal from the mouth.

As materials were improved, so were the technics in their use. Special trays were designed to replace modeling compound; brushes and syringes were substituted for the moldine to cover the prepared abutments with the hydrocolloid. These helped to expedite the technic at the chair and enabled the dentist to have complete control of the time and temperature factors which are so important in the indirect technic for complete accuracy.

All methods and materials used today have their indications and contraindications. While it is true that most restorations can be constructed by the indirect method, those dentists who have for years utilized the direct method can make a wax pattern directly in the mouth in a fraction of the time that it takes to prepare the materials and trays, take the impressions and pour up the models in order to make the pattern indirectly. Even where a technician is immediately available, it is still a matter of judgment whether to make a single, simple wax pattern directly in the mouth or indirectly.

In those instances, however, where there are three or four cavity preparations in the same arch or quadrant of the arch, the indication is for the use of the indirect method. In these circumstances, one impression is utilized to construct a working cast on which the three or four wax patterns and castings can be made and polished at one time.

There are instances where access to the tooth is so difficult that the indirect method is preferable. Or the shifting or rotation of a tooth may make it impossible to place a sufficient amount of hydrocolloid material between the adjacent tooth and the prepared tooth, which might result in a distorted die; in such instances it might be advisable to make the wax pattern by the direct method. No dental material or method is a panacea; each has its place.

RETRACTION OF GINGIVAL TISSUE

If the decision is made to use the indirect method, then it is desirable to make a careful examination of the contiguous tissues. As is well known, the depth of the gingival crevice usually varies with the age of the patient. In the younger patient, there is usually less depth to the crevice; consequently, more difficulty may be experienced in re-

tracting the gum tissue in order to expose the cavity margins. There are other instances in the adult and older patients, where the crevice is unusually deep and is surrounded by a pendulous gingiva which is soft, inflamed, and bleeds easily.

Because all margins of a prepared tooth must be completely exposed and the cavity dry, varying gum conditions must be recognized and a suitable method for the retraction of the tissues must be decided upon.

The several methods available for the retraction of tissues have been described in the literature.^{8,9} It is known that the hydrocolloid impression materials, whether of the agar-agar type or of the alginate type, will not displace soft tissues or fluids of the oral cavity; hence, the necessity for gum retraction. Any technic of tissue retraction must normally be conservative so as not to cause detachment of the tissues from the tooth or injury which may ultimately result in permanent tissue recession.

Extreme precaution in retraction of the gum tissue is especially important when done on anterior teeth. Injury to the soft gingival tissues, whether by traumatic or chemical means, will result in shrinkage after the gum heals. In placing the cervical margin of a preparation beneath the crest of the gum tissue, similar precautions should be taken. The method whereby the rubber dam and clamp are utilized to depress the gum tissue while lowering the cervical margin beneath the gingival crest is an excellent precaution. Cotton thread or wrapping cord is usually used to distend and retract the gum tissues; this also should be done carefully so as not to detach the membrane from the tooth.

Thompson¹⁰ has indicated the following drugs and methods to be useful for gingival retraction. The first utilizes styptics: either zinc chloride 8 per cent, ferric subsulfate (Monsel's powder), tannic acid 20 per cent (full strength), or alum 40 per cent (full strength).

Thread or wrapping cord of the proper thickness is usually impregnated with the drug and then dried. These are later used either in single strands or wrapped around the tooth. When carried into the gingival crevice, the cord not only retracts the gum tissue but the exudate of the gingiva dissolves the drug and its styptic action is utilized to keep the area dry.

If there is no bleeding or seepage, untreated wrapping cord may be used to distend the tissue. When this is done, a vasoconstrictor such as Adrenalin chloride (epinephrine) 1 per cent or ephedrine sulfate 3 per cent may be applied to the cord after it has been tucked into the crevice in order to obtain the vasoconstrictor action of the drug.

Thompson¹¹ suggests that where a loop is formed with the cord a

single knot be utilized, and that after the cord has been gently pressed into the crevice a drop of warm wax be added on the knot to hold the loop taut around the tooth; still, the knot will yield sufficiently if it is necessary to press it further into the crevice.

Some operators remove the cord prior to taking the hydrocolloid impression; others take the impression with the cord in place. If the stronger drugs are utilized, it is inadvisable to let these remain during the impression taking. It is suggested that the treated cord be removed, the tissue washed, dried, and a dry piece of cord replaced into the crevice. If seepage persists, a drop of the Adrenalin chloride may be applied or alum-impregnated cord may be placed for a few minutes.

Some conditions require the removal of hypertrophied gum tissues or those which cannot be retracted successfully by conservative means. For this purpose, chemical cautery is utilized by using cord impregnated with 40 per cent zinc chloride; alternatively, sodium sulfide or potassium hydroxide may be used to cauterize undesirable gingival tissue. Caution is necessary because of the danger of excess tissue destruction. Chemical cautery is also indicated when it is desirable to increase the clinical length of a submerged crown. Following the impression, the tissue should be treated with a mild antiseptic and covered with a pack of the zinc oxide-eugenol, if chemical cautery is used. Such a protection for several days will allow the damaged tissue to heal.

Still another method of radical retraction, if it can be called such, is by means of surgery wherein the tissue is removed either by electric cautery, the knife, or by cold cautery. The usual surgical precautions should be observed and should be followed by the pack previously mentioned.

Failure in properly placing the cotton thread or cord to obtain gingival retraction is largely the cause of disappointment in the use of the indirect method.

To overcome the difficulty of retracting the gum and exposing the gingival margin, particularly in three-quarter and complete crown preparations, a technic has been devised by Pagenkopf¹ which simplifies this step. He describes his technic as follows: "Select a copper band just a little larger than the greatest circumference of the tooth and carefully festoon it. Then, with a pinking-crimping pliers, pink and crimp this gingival edge. This may also be done with a Joe Dandy disc. The occlusal portion of this band is closed with temporary stopping. Then select a washer, stamped out of buckskin, chamois, or felt; saturate it with the astringent and hemostat. Of the many on the market, I have found aluminum sulfate, the styptic pencil used for cuts while shaving, to give the best results. Place the band over the

preparation and apply pressure with the pinked and crimped edge of the band until it forces the washer beyond the gingival line. Continuous pressure may be exerted by having the patient apply force on the band with his opposing teeth. The pinked and crimped bands prevent the washer from slipping either inside or outside of the band and defeating its purpose. This is left for about ten minutes after which time the impression can be taken." Those using this technic can attest to its simplicity and effectiveness.

If a ready-made tray is to be utilized for taking the impression, it should be sufficiently large to allow for at least $\frac{1}{4}$ inch thickness of impression material, so that if undercuts are present there will be sufficient bulk of impression material to allow it to pass over these without permanent distortion. Likewise, the tray should be long enough so that the impression extends beyond the prepared teeth and includes at least one or two teeth in either direction.

In order to prevent the tray from being carried too close to the occlusal surface of the teeth, a small amount of modeling compound is placed at either end of the tray beyond the prepared teeth; these "stops" assure a sufficient thickness of the hydrocolloid material in the finished impression over the occlusal area of the prepared teeth. As previously mentioned, there are two types of hydrocolloid impression materials: the reversible and the irreversible. The base for reversible dental hydrocolloid is agar-agar, which is derived from sea plants; it can be liquefied by boiling and cooled to temperatures which can be tolerated by the tissues of the mouth. It changes to an elastic gel at a temperature of approximately 99° F. The change of the material from its liquid to its gel form is accomplished by flowing water at 50° to 60° F. through the water-cooled tray. However, the change from the gel to the sol takes place at 108° to 126° F.

On the other hand, if a colloid sol is changed to a gel by a chemical reaction, and if the gel cannot be returned to a sol state by ordinary means, then the hydrocolloid is classified as irreversible. The alginate impression materials are of this nature. Their change of phase from a liquid to a gel state is not the result of a temperature change but is due to a chemical reaction between sodium alginate and calcium sulfate. More shall be said of the alginates later.

REVERSIBLE (AGAR-AGAR) IMPRESSION MATERIAL

Equipment

In addition to the perforated water-cooled trays, certain other equipment is desirable in order to assure the successful use of the re-

versible hydrocolloid technic. This includes a small syringe for injecting the liquid hydrocolloid into the prepared cavities; a large syringe for liquefying the hydrocolloid which is to be used in the impression tray; and finally, a conditioner, preferably with automatically controlled water baths for the liquefaction, storage and tempering of the impression material. With such equipment, it is possible to liquefy the hydrocolloid to the proper temperatures and place it in the mouth without injuring the tissues.

Procedure

There are seven steps in the general procedure of using the reversible hydrocolloid:

1. Liquefying the material by boiling it for at least 8 minutes.
2. Storing the boiled material in the syringes or tubes at a temperature of 150° to 155° F. and holding it at this temperature until ready for use.
3. Lowering the temperature of the tray material by placing it in the tempering chamber at a temperature between 102° and 115° F., and holding that temperature between 5 and 15 minutes.
4. Injecting the fluid hydrocolloid through the needle in the small syringe into the prepared teeth.
5. Removing the tray with its tempered material from the tempering bath and carrying it to the mouth, after scraping off the top layer which was exposed to the water.
6. Changing the sol into the gel by circulating water at 50° to 60° F. through the tray.
7. Removal of the impression from the mouth and pouring of the casts or dies in artificial stone.

Liquefaction. The first step is the proper liquefaction of the gelled material as it comes from the manufacturer in the sealed tubes or in the syringes. A minimum of 8 minutes' boiling time is indicated for fresh materials. Whenever unused hydrocolloid is allowed to gel and is later reboiled, it will require the addition of several minutes to the original 8 minutes ordinarily required for fresh material. Boiling for a reasonable length of time beyond 8 minutes will cause no harm to the hydrocolloid.

At high altitudes where the boiling point of water is reduced below 212° F., it may be necessary to use pressure cookers in order to liquefy the material.

Storage. Once the material has been liquefied, either in the syringes or in the manufacturer's tube, it may be placed in the storage chamber at a temperature of 145° to 150° F. until ready for use. When an automatic conditioner is used, the material may be boiled at the beginning

of the day and stored at this temperature; it will then be ready for use at all times. The storage temperature should not be allowed to drop below 145° to 150° F. because it may start to gel and be too stiff to be flowed easily into the prepared teeth. When the material is boiled and is to be used immediately, it should be placed in the tempering bath of 150° F. and kept at this temperature for at least 8 minutes to bring the temperature down from the boiling point.

The hydrocolloid in the small syringe is kept in the storage bath at a temperature of 150° F. until ready for injection in the tooth. The material in the larger syringe is used for filling the tray; it must be additionally cooled later in the tray by being tempered to 102° to 115° before insertion of the tray into the mouth.

Tempering. The tempering of the impression-tray material causes a partial gelation and stiffening of the mass of material; also, it is more comfortable thermally to the tissues. If the hydrocolloid in the tray were placed in the mouth at a temperature of 150° F., not only would it be uncomfortable to the tissues but it would be so liquid that it would flow out of the impression tray and away from the teeth and tissues. Tempering of the tray material is accomplished by various combinations of time and temperature.

If 102° F. is used, the filled tray should not be left in the tempering bath longer than 2 minutes. If 105° F. is used, then 5 minutes; if 110° F., then 5 to 10 minutes; if 115° F. is used, it may be left up to 15 minutes before being placed in the mouth. It must be remembered that gelation depends on coordinating the two factors of time and temperature.

Having been previously adjusted for size in the mouth, and the modeling-compound stops having been fitted for proper height and centering in the mouth, the tray is filled and placed in the tempering bath. Meanwhile, the dentist dries the cavity and completes the gum retraction.

Injection. Next, the small syringe is removed from the storage chamber where it has been held at a temperature of 150° F. Because of possible water contamination of the hydrocolloid within the needle of the syringe, it is advisable to extrude a small amount of the material on the finger to clear the syringe needle. While the hydrocolloid is still flowing out of the needle, it is carried to the gingival area of the distal surface of the posterior preparation and the material is forced into the embrasure until it flows out buccally and lingually; the needle point is then brought upward in contact with the tooth surface and carried mesially. Maintaining contact with the tooth, it is carried down to the mesiogingival wall where more material is injected until the embrasure is filled to overflowing buccally and lingually, as well as the

adjacent teeth on each side of the preparations. This procedure should be accomplished rapidly, otherwise the hydrocolloid coming in contact with the relatively cool tooth may gel to the degree that when the tray material is brought in contact with it later, the hydrocolloid covering the prepared tooth will not be compressed against the walls and sharp angles of the cavity to record the details of the preparation.

Transfer of Tray from Bath to Mouth. When the abutment and adjoining teeth have been covered by use of the small syringe, the filled tray is removed from the tempering bath and the water-contaminated top surface of hydrocolloid is scraped free. The rubber hoses for the circulation of water are attached to the tray, and it is placed in the mouth so that the anterior and posterior compound stops come in contact with the unprepared anterior and posterior teeth.

Gelation. The tray, with the water circulating, must be held firmly in position without undue pressure and allowed to chill until complete gelation has taken place. This requires from 5 to 7 minutes, depending upon the material used. It is advisable not to use ice water but a water temperature of approximately 50° to 60° F.

The impression must not be removed before complete gelation has taken place. If the material is incompletely gelled, there will be a distortion of the impression and an inaccurate stone die or cast will result.

Any movement of the tray must be avoided during the gelation period. Both lateral and vertical pressures must be avoided.

Removal of Impression from Mouth. After gelation has taken place, the impression is removed with a sharp occlusal pull in a direction parallel to the long axis of the preparations. Removing the tray with a rocking motion will result in distortion; also, fracture is more likely to occur. The removal of the impression should not be attempted by raising the handle of the tray; a finger is placed on the periphery of the material on each side of the tray and the tray is then quickly pulled vertically away from the teeth.

After the tray has been removed from the mouth, it is examined carefully for sharpness of cavity outline or distorted and ruptured areas. If satisfactory, the impression is gently washed in water at room temperature.

Pouring of Casts or Dies. To accelerate the setting of the stone die or cast which is poured in the impression and to give a smooth, dense surface to the stone, it is advisable to place the impression in a 2 per cent aqueous solution of potassium sulfate for a period not to exceed 5 to 10 minutes. During this time, the stone and water are mixed in proper proportions and the impression is ready for pouring.

Hydrocolloid impression material consists of approximately 80 per

cent water; therefore, if it is left exposed in the open air, it will lose some of its water content with a resultant shrinkage. This is one of the most frequent causes of failure in the use of the indirect method. No hydrocolloid impression should be left exposed in air longer than 2 or 3 minutes.

The false impression sometimes prevails that the water which is lost by evaporation or syneresis may be restored by placing the impression into water so that it may absorb the amount which has been lost. While it is true that the hydrocolloid will imbibe the amount of water lost, it will be done at the expense of a distorted die or cast owing to the release of stresses within the impression. If, for some reason, the impression cannot be poured immediately, the next best precaution is to place it in an atmosphere of approximately 100 per cent humidity until such time as it can be poured, but not exceeding 30 minutes. While this does not eliminate entirely the possibility of distortion, it will be of lesser degree than if the impression were left in the air or placed in water.

Before pouring the cast, all excess and droplets of the potassium sulfate solution are carefully blown out of the impression. Care, however, should be exercised not to dehydrate the hydrocolloid surface.

Only the newer hydrocal stones should be used to pour the dies and casts. These stones have been specially prepared for the indirect technic; they possess a minimum amount of setting expansion and a maximum surface hardness and smoothness. The manufacturer's directions and water-powder ratio should always be followed if one desires to obtain smooth surfaces as well as a strong die. The use of mechanical mixing, especially under vacuum, tends to assure smoother, denser and stronger dies.

After the stone has been properly mixed it is ready to be placed into the impression. Phillips⁴ has shown that the rate at which stone is flowed into the impression has a very significant effect upon the surface of the die; likewise, the amount of vibration which accompanies the flowing of the stone into the impression. It has been found that if the stone is added in large quantities, accompanied by excessive vibration, there is a tendency to entrap air bubbles and produce nodules in the finished die. It is important to fill the impression by placing small increments of stone in one section of the impression and allowing the stone to flow into other parts of the impression from this initial point of application.

After the stone is poured in the impression, two procedures may be followed. One is to place the poured impression in a humidor of 100 per cent relative humidity; another, is to submerge the poured impression in a 2 per cent potassium sulfate solution for 15 minutes, after

which it is removed and allowed to set for one hour. The investigations of Phillips and Ito⁴ tend to favor the first method, as the dies made in this manner gave a slightly smoother surface.

They also found that the immersion of the poured cast in the potassium sulfate solution tends to prevent deleterious effects on the surface of the stone die if it is not removed from the impression within one hour. It is suggested, however, that stone dies and casts be removed from the impression one hour after they are poured. On the other hand, sufficient time must be allowed for the stone to set before the cast or die is separated from the impression. If it is removed too soon, there is a tendency towards a pitted and chalky surface. After removal from the impression, the die or cast should be set aside and no work done on it until 24 hours have elapsed.

The investigations of Peyton, Leibold and Ridgley² indicate that the dry crushing strengths of stone are greater than the wet; also, that oil immersion treatment of dies and stones decreases their crushing strength.

IRREVERSIBLE (ALGINATE) IMPRESSION MATERIAL

Laboratory experiments have shown that the alginate impression material is as accurate as the reversible type.⁶ However, its limitation as an impression material for cavity, crown, and bridge impressions lies in the fact that it has a comparatively short working time. This does not allow sufficient time for the operator to fill the cavity and the tray, and still have time left to carry the tray into position while the material is in its sol condition. As a result, there frequently is a lack of union between the material covering the tooth and that in the tray.

Efforts have been made to increase the setting time of the alginate material by utilizing ice water and chilling the plaster bowl and spatula.

If an alginate hydrocolloid is selected for cavity and bridge impressions, then a type of material must be used which has the necessary viscosity without changing the water-powder ratio as recommended by the manufacturer. Such a material should possess a gelation time of 6 to 8 minutes at room temperature.

It has also been found⁵ that when alginate hydrocolloid is applied to a dry surface there is adhesion of the material to the tooth; consequently, a better impression is obtained when the surface is not completely dried. However, although the surface must not be desiccated, there should not be any free saliva in the cavity when the impression is taken.

Generally, it has been found that the reversible hydrocolloids are more suitable for the indirect technic in operative and crown and bridge restorations, whereas the alginates find greater use for im-

pressions involving removable partial dentures and as a wash for complete dentures.

If alginate hydrocolloid is used for cavity impressions, then the same precautions and methods of tissue retraction are employed as for the reversible hydrocolloid.

Any type of hydrocolloid impression material is stretched and stressed upon removal over undercuts. Stresses, when released, may cause discrepancies in the finished dies or casts; these are found to be more nearly negligible in removable partial denture casts than in dies of prepared cavities.

Attempts have been made to combine the two types of hydrocolloid in one impression;⁷ since there is no union between the two materials, other than a mechanical one, there is danger of a distorted die or cast.

Because the change from the sol to the gel is the result of a chemical reaction and is not dependent upon change in temperature, it is not necessary to use a water-cooled tray; however, in order to lock the gelled material securely within the tray it is necessary to use a perforated tray or a rim-lock type. If the gelled material should be displaced accidentally from the tray, the impression will give a distorted cast, and such an impression should not be used.

As with the reversible hydrocolloids, the alginate impression should not be left standing in the air, since it will lose moisture and contract; nor should it be stored in water, as it will imbibe water and become distorted. If it must be stored for a short time, it should be kept in an environment of 100 per cent relative humidity.

The successful use of the alginate hydrocolloid depends upon the correct lapse of time between its spatulation and placement in the mouth. It is well to make a preliminary mix using water at 70° F., and to determine the initial and final set of a new batch of hydrocolloids. Most of the alginates on the market today have an initial set of 2 to 3 minutes and a final set of 3 to 4 minutes, a total of 5 to 7 minutes. The time of final gelation is usually measured from the beginning of the mix until the final set has occurred. Once the gelation has started it must not be disturbed, since a distortion will result.

It must be remembered that the alginate hydrocolloid is of relatively recent manufacture. Investigation has shown⁸ that materials stored for one month at 65° C. were unsuitable for dental use, were unreliable as to their setting time and had decreased in compressive strength. As the temperature was lowered to 50° C., deterioration also took place but more slowly. When the material was stored at a temperature of 37° C., it showed no deleterious effects. Consequently, if a large supply of the material is to be stored, it should be kept at low temperatures. This may answer some of the unexplainable dimensional

instability of alginates that has been observed even when all other variables have been held constant.

Whether to place the alginate impression in a fixing solution or not depends largely on the product used. Some manufacturers advocate and furnish a fixing solution with their material, but the more recent types of hydrocolloids do not require this additional treatment. If the fixing solution is advocated by the manufacturer, it should definitely be used since it will hasten the setting and prevent any surface softening of the stone die or cast.

Some dentists recommend that after the stone die or cast has been poured into the impression both be placed back into the fixing solution, usually a sulfate. In any event, the impression should never be left exposed to air for any length of time; neither should it be exposed to tap water longer than required to wash off any debris or saliva. If the impression is immersed in a hardening or fixing solution, ten minutes should be enough for the surface layer of the gel to obtain a sufficient hardening effect.

As with the reversible hydrocolloid, the stone cast or die should not be removed from the impression before one hour. This is true even though the hydrocolloid requires the use of a hardening solution prior to pouring the cast. Also, it has been found inadvisable to place the poured cast and impression in tap water while it is setting; the resultant cast will have an inferior surface.

* * * * *

The dental literature is replete with excellent articles on the uses of both reversible and irreversible hydrocolloid impression materials for the construction of individual inlays, crowns, bridges, partial dentures, complete dentures, and obturators. (See *General References* at end of this article.)

Due credit must also be given to the manufacturers of both the reversible and irreversible hydrocolloids who, during the past twenty-five years, have done scientific research in their own laboratories and who have given their findings to the dental profession.

The profession is currently exploring a new horizon in the field of impression materials, namely, the Thiokol and silicone elastic materials, which are discussed elsewhere in this symposium.

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Plaster and Stone

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Plaster is surely the most prosaic of all dental materials; it is a veritable Cinderella—very useful, but mostly subservient to some purpose which no longer has need of it. Its harder and more expensive sisters, artificial stone and die stone, are treated with more respect perhaps, but all suffer from inherent weaknesses which call for a reasonable amount of care in handling.

There has been comparatively little advancement in recent years regarding the practical application of these familiar laboratory materials, but what work has been done is worth recording. On the other hand, the latest research on the mechanism of setting of calcined gypsum products is of great theoretical interest, but because it has had no appreciable bearing so far on the use of the products in dental practice it will not be reviewed here.

SELECTION OF PRODUCT

Unfortunately, at the present time the List of Certified Materials issued by the American Dental Association does not extend to plasters and stones and so cannot serve as a guide in the selection of a suitable product. However, the American dentist is fortunately placed in regard to the excellent quality of gypsum material available to him, which is undoubtedly the result of efforts on the part of manufacturers to meet his special needs and to exercise careful control of the products so developed.

Particle size, setting time, expansion and strength are the important physical factors and some manufacturers furnish these data on the product label. According to Australian Standards,¹⁹ laboratory plaster should set in 5 to 20 minutes, expand 0.05 to 0.20 per cent in 2 hours and withstand a crushing force of 1,400 pounds per square inch (psi) 1 hour after the commencement of mixing. Artificial stones are required to set in 5 to 30 minutes and to withstand 3,000 psi; the modern

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"ultra-strength" die stones would be expected to go even higher. These figures are "green" or wet strengths, and the strengths for the dry material would be 2 or 3 times greater.

The Australian Standard for artificial stone provides for two types, low-expanding and high-expanding. The low-expanding type has the same limits as the laboratory plaster, these being chosen for faithful reproduction. By providing an oversize model, the high-expanding type is intended to compensate for the contraction of denture base resin on processing. Its expansion requirement is 0.30 to 0.45 per cent, but it should be remembered that if these stones are allowed to set under moist (hygroscopic) conditions the expansion can be nearly doubled.³

It has been pointed out that expansion figures given by compensating stones bear little relation to the processing contraction of acrylic resin, particularly since this is not uniform in every direction owing to the ridges and other irregularities in the shape of a denture. However, one can work on the principle that some compensatory expansion of the model material would be useful unless it is considered that a slight contraction in a denture base will improve retention. As far as metal partial dentures are concerned, it has been reported that it has not been possible to detect any differences in the fit whether they were made on normal or expanding stone casts.²

The choice of type of gypsum product for any dental application depends chiefly on the strength and surface hardness desired, and these range from the mechanically weak impression plaster to the hardest die stones. In the flasking of dentures it may be advisable to use materials of different strengths for the various pours. The use of the harder stones for the splint or third pour of the flask, for example, has been shown to minimize the opening of the bite on processing. The change in vertical dimension is decreased, but not eliminated, by so reducing the shift of the teeth when pressure is exerted in the flask.¹⁰

For economy or other reasons it is sometimes considered necessary to have gypsum materials intermediate between those supplied commercially. It has been found that it makes no appreciable difference whether plaster and stone are first mixed as powders or whether they are added separately but in the same proportions to the water in the mixing bowl. Tests show that the strength and hardness of such mixtures are intermediate and proportional to the relative quantities used, but this holds true only if the water-powder ratio is adjusted in the same proportion.¹

The proper storage of gypsum products is still often neglected. Moisture contamination by liquid or vapor allows the formation of extra gypsum nuclei, thus accelerating the hardening. Ultimately, with

the absorption of more water the apparent setting time is lengthened and the material weakens considerably. In fact it is considered that it is this weakening of the product that eventually necessitates a longer time before it can support the setting time testing needle.

WATER-POWDER RATIO

The mixing ratio is the key to the proper use of gypsum products. Plaster, artificial stone and the extra-strength die stones differ physically but are based on the same chemical entity—calcium sulfate hemihydrate. Their chief physical difference lies in the compactness and uniformity of the crystals. The stones are based on gypsum partially dehydrated under steam pressure which gently regulates the escape of water through the layers in the crystals, leaving them more or less intact. Ordinary plaster is calcined by direct and rapid heating which drives out water with some violence so that the gypsum is shattered into irregular and more open crystals.

This crystalline difference affects in two ways the amount of water required to give a mixture of the desired working consistency. First, for a given proportion of solid to liquid in a slurry the one with the more regular particles will pour more readily. Second, with crystals that are dense and uniform, relatively more water is available to contribute to the fluidity of the mix because less is taken up in filling up the irregularities and voids. Hence with an artificial stone less water is required for a given consistency than with plaster.

Unless the product has been modified with foreign substances to weaken it or to alter its crystal growth habit, the compressive strength of the set material depends ultimately on the quantity of dry solid material that is packed into a given volume. This must depend largely on the proportion of water added originally, since the dimensional change on setting is small. About 18 parts of water are required to hydrate 100 parts of powder in order to reconvert it to gypsum. Some extra moisture is loosely held but most of the remainder evaporates, leaving behind a corresponding distribution of voids in the mass.

Thus a laboratory plaster requiring 40 to 50 parts of water to 100 parts of powder by weight for a satisfactory working consistency will usually give a 1 hour strength of 1,400 to 2,000 psi, while artificial stones with a water-powder ratio of 0.30 to 0.40 will give strengths of 3,000 to 4,000 psi. The more recently developed extra-hard die stones may have a water-powder ratio down to 0.20 with strengths of over 5,000 psi at 1 hour.¹ The fact that these die stones are nearing the theoretical limit of the water required for reaction indicates how dense and compact the constituent crystals must be.

For best results with plasters and stones the water and powder should be correctly proportioned, and thick mixes, consistent with the operation in hand, will give a harder product. A thinly mixed artificial stone can be weaker than a thickly mixed plaster; there seems little point in purchasing a stone at a much greater price only to make it as weak as plaster by using a "sloppy" mix.

However, there is a limit to the thickness of the mix one can use. A stage is reached at which the material becomes unworkable, but even before this, while still in the putty-like range where it is possible to cause the mixture to flow by vibration, there is a marked falling-off in strength. Moreover, judging by the scatter of results obtained, the mixes are not as uniform and reproducible as they should be.⁶

The water-powder ratio recommended by the manufacturer can usually be relied upon to give the optimum properties for a particular product.

SPATULATION

The importance of adding the powder to the water in a rubber mixing bowl and the need for thorough and even mixing is elementary knowledge but there may still be some doubts about the merits of accessory mechanical and vacuum devices.

It has been demonstrated that the uncontrolled "average" technique of mixing plaster produces inferior physical properties and much greater porosity due to the incorporation of air bubbles.⁸ Porosity at the surface is undesirable; for example, it may result in nodules on the acrylic denture or, unless filled in, it may give a poor esthetic effect on orthodontic models.

Sifting instead of dumping the powder into the bowl produces less porosity, and the use of the conventional flexible rubber bowl rather than a glass bowl allows slightly better spatulation and hence less porosity. Either vacuuming the mix before pouring or the use of power-driven spatulation increases the strength of the plaster used. Vacuuming reduces the number of bubbles but the few that remain are relatively large, whereas mechanical spatulation, while not eliminating as many voids, breaks them down to a much smaller size and produces the most consistent and uniform results.

Some experiments have been reported on the mixing of plaster by centrifuging, whereby a thin mixture is centrifuged and the excess water poured off. The effect on strength is not conclusive but it is interesting to note a marked increase in setting time.²¹ This is, of course, a consequence of the absence of spatulation which is normally instrumental in breaking up gypsum crystals as they form, thus providing a greater number of fresh nuclei for subsequent crystal growth.

POURING THE CAST

Casting a model or die may be a simple procedure, but two of the hazards are trapping of air bubbles and distortion of the impression. Vibration improves the fluidity of thick mixes of stone, and air bubbles have a better chance of escaping. However, distortion of flexible impression materials can result if the consistency of the stone is too thick or if vibration is excessive. One of the ways of producing relatively gross distortion of the impression is to invert the filled impression and press it firmly down into a heap of stone on the bench.¹³

In flasking procedures the trapping of bubbles in interproximal spaces can be minimized by first scrubbing a thick mix of stone over the wax denture with a small soft-bristled tooth brush until a thin layer covers the wax and teeth. The remainder of the investment can then be placed quickly to complete the upper half of the flask, avoiding any dangers of vibration.²²

Centrifugal methods of casting have been attempted.^{14,15} Strength and surface hardness were increased in the experiments, probably owing to the removal of some residual water, but a noticeable increase in the number of air bubbles has also been reported.

SURFACE QUALITY

For satisfactory models a smooth hard surface is essential. When it comes to dies for the indirect method in the preparation of inlays, crowns and bridges, even the most improved stones fall short of the ideal in resistance to abrasion, and various attempts have been made to make good this deficiency.

First there is the question of smoothness. Apart from porosity arising as a result of mixing and pouring, there is the effect of the impression material itself on the plaster or stone. This matter has received considerable attention and the conclusions may be summarized. For best results in hydrocolloidal impressions, whether agar or alginate, it is impossible to lay down general rules for their treatment prior to pouring the cast. Too often certain conclusions have been reached on the basis of tests with one impression and one stone and these conclusions have then been assumed to apply to hydrocolloidal impressions and stones in general. The classic example is the use of the frequently advocated 2 per cent potassium sulfate hardening or "fixing" solution which with some combinations will actually reduce the hardness of the surface or even result in a definite chalkiness.¹⁸

Unless the practitioner is prepared to conduct a series of experiments of his own the only advice that can be given is to follow the manufacturer's directions. If the surfaces he obtains are still unsatis-

factory the matter should be taken up with the manufacturers of both the impression material and the stone.

Obviously, the impression should be free of droplets of water or fixing solution. In blowing away or otherwise drying off this water care should be taken not to dehydrate the impression itself, as this can also result in a rough cast surface.¹⁶ Thin mixes of stone have been found to produce inferior surface properties and here again it is essential to use the optimum water-powder ratio—not too thin or too thick.

As previously pointed out, the stone should be poured into the impression with mild vibration only, and then the cast and impression should be left together for about an hour before separation.^{16,17} During this time they should neither be placed in water nor left exposed to the air, but preferably in an atmosphere of 100 per cent relative humidity. This can be achieved with damp towels or by using a humidor.

Whatever method is used it seems impossible with hydrocolloids to produce a surface quite as good as that obtained when the stone is set against glass.¹⁸ Better surfaces are obtained with the mercaptan rubber base and silicone base elastic impression materials, although considerable trouble was experienced with earlier products of the latter type if the cast was poured soon after the impression was taken. The rough surface was found to be due to "gassing" resulting from the liberation of bubbles of hydrogen in the impression. The phenomenon was most noticeable with the first products based on raw material made in Germany, but the catalysts have now been modified to eliminate this effect; products based on silicone of American origin are apparently not susceptible to this defect.

In prosthetic work the surface quality of the set gypsum can be affected by hot water used to eliminate wax from the denture flask. Gypsum is inclined to be regarded as insoluble but this is far from the case; it has a maximum solubility in water of about 0.26 per cent at 40° C. and slightly less at lower or higher temperatures. Prolonged treatment with water, especially warm tap water, can erode the surface and spoil the detail, particularly if the gypsum was prepared from a thin mix.⁷

The extra-hard improved die stones are subject to thermal shocks when dry, and boiling water should not be poured onto a dry die. Such dies should first be soaked in water.

SURFACE HARDNESS

Surface hardness is closely related to bulk compressive strength but it reaches its maximum somewhat more rapidly because the surface is

the first to dry out. According to the setting rate, hardness increases rapidly after the stone is poured until hydration is complete. From this point the hardness remains fairly constant until most of the excess water has evaporated, at which time another large increase is experienced. It is often not practicable to wait until this maximum strength is developed but at least one should wait until the initial hydration is completed, usually 1 to 2 hours after mixing.⁹

Various treatments have been advocated for increasing the surface hardness of gypsum models or dies. Soaking in a saturated solution of borax gives a marked improvement in the hardness of plaster models but this was not found to be the case with the stones tested.¹⁸ Soaking in water, glycerin or oil was not found to improve the surface hardness or abrasion resistance and it definitely reduced the crushing strength of the stones investigated.^{5,15} Neither did immersion in a stearic acid bath nor coating with petrolatum result in any hardening.¹⁸ The effect of oils, greases or waxes is apparently due not to any hardening but possibly to the smoothness produced such that a wax carver is not as likely to cut the stone as it glides or skids over the surface. It has been pointed out that this phenomenon may inspire a false sense of security in the operator by virtue of an appearance of surface hardness which does not exist.¹⁸

Perhaps we can look to the use of synthetic resins to improve the surface hardness of stones. There are promising results in the industrial field in this direction.¹¹ In some reports it has been claimed that resistance to abrasion can be increased 6 to 8 times by the addition of a carbamide (urea) resin to the mix. Others have demonstrated no improvement in hardness with a resin-incorporated stone, but the type of resin was not indicated.¹⁸

DIMENSIONAL STABILITY

While set gypsum models undergo detectable changes in dimensions, particularly with variations in moisture content, the magnitude of the changes under normal conditions of storage is too small to be of clinical significance if the dimensional changes on setting allowed by standard specifications for these products are any criterion.^{5,20} Overheating of gypsum is accompanied by loss of water and shrinkage and so is contraindicated.

SEPARATING MEDIA

The surface of gypsum often needs to be treated to aid separation from the pattern wax or the cured acrylic resin. Glycerin, oil or petrolatum can be used for dies in the indirect technique without harmful

effects.⁵ For acrylic denture work, the model and investment should be coated with tinfoil for ideal results, but from the practical point of view alginate separating media are more convenient. In spite of the fact that the latter and other tinfoil substitutes have been shown to cause whitening of the denture and to increase its susceptibility to crazing,⁴ it is claimed that in Britain, where they are used almost exclusively, there is nothing in clinical evidence to suggest that their effect upon the finished denture is in any way harmful.¹²

Investigations in Australia have shown that the whitening effect obtained with alginate separating media is greatly aggravated when there are traces of phosphates remaining in the acrylic resin after emulsion polymerization. The defect is probably the result of the migration of calcium ions from the gypsum through the permeable alginate film to form precipitates in the surface layer of the resin. Manufacturers should ensure that phosphates and other substances likely to cause this defect are eliminated from their products.

Commercial alginate products vary greatly in their effectiveness depending on the molecular weight of the alginate and the presence of modifiers such as trisodium phosphate. Painting the film with calcium chloride solution may improve its performance.

SUMMARY

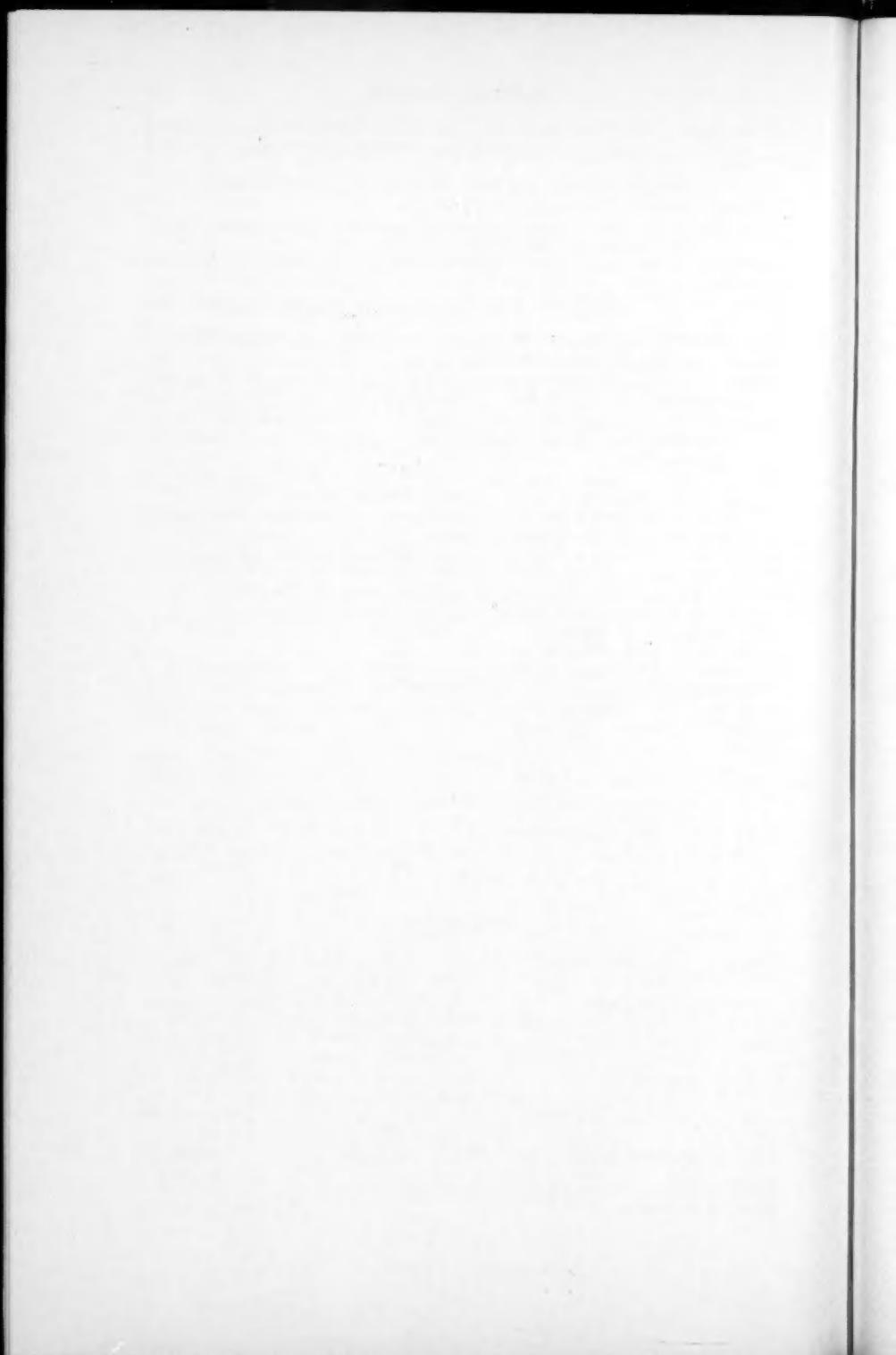
Although plasters and stones are commonplace materials, they require care in handling for best results. This entails the selection of suitable products for the work in hand, correct proportioning for optimum strength and hardness, careful spatulation and pouring to minimize porosity and adequate precautions concerning any impression materials and separating media that come into contact with them.

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Modern Rotating Instruments— Burs and Diamond Points

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The removal of tooth structure for the accomplishment of restorative dentistry has always been associated with patient discomfort and pain. Early efforts to reduce these disturbing factors resulted in the development of a bur-like instrument with a handle that could be rotated in the hands, and which supplemented the chisel and excavator. This simple device permitted more effective operating, as its multiple blades attacked tooth structure and disrupted it in a series of small particles or chips. Heat production was probably very slight because of the low speed of rotation and intermittent contact with the tooth, but cutting efficiency was very low.

With the advent of the dental engine, burs were developed having various shapes and cutting characteristics suited to the particular form and outline of the preparation. Abrasive instruments made of materials such as carborundum were employed in an effort to attack the enamel more successfully, since burs were poor cutters of this hard tissue. The unpleasant sensations associated with cutting teeth were only slightly affected by these early improvements, and it was not until the local anesthetics became available that an actual reduction in pain was possible. In spite of the widespread use of local anesthesia, a session in the dental chair still ranked as one of the more unpleasant experiences.

Research efforts of the past few years have revealed many facts concerning the manner in which dental burs and abrasive instruments operate. Studies of cutting effectiveness and the use of high speed motion picture photography of rotating dental instruments have pointed the way to improvements in manufacturing and methods of use of these instruments.

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The abrasive wheels and cylinders of the molded type have largely given way to instruments coated with diamond particles held in place by sintered or electrically deposited bonding material. These diamond abrasive instruments have particular advantages in that they are capable of maintaining their special shape with repeated use.

The modern bur is made of hardened steel or tungsten carbide. It is quite precise considering its low cost, and it has contributed significantly in the search for improved methods for removing tooth structure. The use of this instrument has been the subject of many studies involving such factors as the problem of heat generation, efficiency, vibration characteristics and life expectancy. Each of these factors is influenced by several variables, such as size, design, speed or operation and force applied. The works of Walsh and Symmons, Peyton and Vaughn, Jeserich, Ingraham and Tanner, Nelsen, Borden and others have contributed immeasurably to present-day knowledge of these cutting instruments. A significant contribution toward the reduction of patient discomfort has been the emphasis upon the requirement for temperature control during cavity preparation. Henschel, and others, have for many years advocated the use of a stream of water, or water and air, as a coolant to control pain and trauma due to frictional heat during cutting. A water spray was found to be most practical for clinical application.

Manufacturers of rotating cutting instruments maintain close relationship with the dental scientist and constantly improve design and production control through their own research facilities. The success with which the dentist uses this information and these instruments, and the degree of reduction of the trauma, both physical and psychic, resulting from their use, are largely dependent upon his application of these recently improved instruments and technics.

Cavity preparation in restorative dentistry has been well developed theoretically. High standards have been set for the physical and biological requirements of operative procedures. The classic principles of outline form, resistance form, retention form and extension for prevention all are based upon sound theory and proven by practice. Until recently, however, the instruments required to accomplish these ideals in the procedures of restorative dentistry involving removal of tooth structure have been numerous, somewhat ineffective, and productive of considerable discomfort.

TERMINOLOGY

For the purpose of clarification of the various terms employed in this discussion, the speed ranges currently available will be delineated

by groups, according to the rotational speeds achieved at the cutting instrument with the various types of dental handpieces. The term *conventional* refers to handpieces which rotate the instruments at up to 12,000 rpm. The term *high speed* refers to handpieces which rotate instruments from 16,000 to 30,000 rpm. *Super speed* refers to those handpieces which produce instrument speeds in the range of 40,000 to 80,000 rpm. *Ultra speed* handpieces produce speeds in the range of 100,000 to 250,000 rpm and above.

CUTTING VERSUS GRINDING

Mechanical removal of hard tooth structure is accomplished by means of steel or carbide burs which are actually small *milling cutters* and by rotating abrasive instruments which are *grinders*.

Milling

Milling cutting requires that the instrument pass rather slowly through relatively soft materials, producing a true chip with each blade. These chips are provided with escape routes through the grooves between the blades. Bur design varies with each manufacturer and with the method employed in fabricating and machining the instrument, but the basic milling cutter concept is found in all types, sizes and shapes. Dynamic studies of the operating bur coupled with laboratory experiments on cutting efficiency have shown that burs are poor cutters of enamel because their milling characteristics do not come into play. In dentin, the bur performs as it should, forming true chips and removing far more material per unit of operating time at a given pressure and speed of rotation than it does in enamel. This does not imply that the bur will not be *effective* in removing enamel, as it is in the ultra speed range, but that it is inefficient and produces excessive heat and vibration. Steel or carbide burs will not remove enamel efficiently or effectively if rotating in the conventional or high speed ranges.

Carbide burs begin to cut effectively in the super speed range, although their life is relatively short because of excessive pressures. Ineffective cutting results in an attempt on the part of the operator to improve the action by the use of heavy pressures. Steel burs rapidly dull under these conditions; carbide burs will perform somewhat more effectively simply because the harder material resists dulling. Carbide is a brittle material, and blade breakage or even neck breakage will frequently occur under the conditions of low peripheral speeds and heavy pressures.

Carbide burs cut very effectively if rotated in the ultra speed range; their life is extended indefinitely by the very light pressures. Steel burs, however, will dull rapidly under these conditions.

Grinding

Removal of tooth structure by grinding with abrasive instruments is accomplished by means of a combination of crushing and friction at each of many contacts of the points of abrasive. Grinding is the method of choice for reduction of very hard materials in industrial application; the same principles apply to the removal of tooth enamel.

Large diameter diamond abrasive instruments ($\frac{1}{4}$ to $\frac{3}{4}$ inch) will operate satisfactorily in the conventional speed range if water lubrication and light pressures are employed. The use of moderate diameter diamonds ($\frac{3}{16}$ to $\frac{1}{2}$ inch) will effectively remove enamel at rotating speeds of 16,000 to 30,000 rpm. Smaller diamond points do not have adequate peripheral speeds when operated at speeds below 40,000 rpm. The use of small points and wheels at slower speeds results in a rapid loss of the abrasive because of the heavy pressures employed in order to cut effectively. Diamond instruments which have been discarded as no longer clinically effective show loss of the abrasive at relatively small areas or points. The other surfaces show little or no loss of diamonds. These areas of breakdown occur where the instrument is repeatedly subjected to the highest pressures per unit area during the performance of exacting cuts in shaping a preparation. Commercial grinding practice calls for wheel surface speeds of from 5,000 to 7,000 feet per minute. Dental diamond points $\frac{3}{32}$ inch in diameter have a peripheral speed of only 720 feet per minute at 30,000 rpm. In order to obtain the recommended peripheral speed for effective removal of tooth structure, these small instruments require rotational speeds of approximately 245,000 rpm. Satisfactory results and long life for small diamond instruments are dependent upon the use of light pressures and the highest possible rotational speeds.

THE GENERATION OF HEAT

A considerable amount of the energy expended by bur blades or abrasive points during the removal of tooth structure appears in the form of heat. An increase in speed produces more heat at the point of contact of the rotating instrument with the tooth. During inefficient cutting more heat is produced, and with the greater pressures and prolonged instrument-tooth contact during ineffective burring or grinding, more heat is transferred through the enamel and dentin to

the pulp. The greatest heat production during removal of hard tooth structure occurs in the ultra speed range; burs and diamonds can produce incineration with incandescence of enamel and dentin. The odor of burning organic material is frequently apparent during ultra speed cutting, even though a coolant spray is in operation. A concurrent rise in pulp temperature does *not* occur, however, because of the reduced time of contact of the blades or abrasive points and the effect of the coolant, together with the light pressures and more effective chip and particle removal. A coolant spray of water or water and air must always be employed during the mechanical removal of tooth structure at all the currently available speeds.

INSTRUMENT ECCENTRICITY

Eccentricity in rotating grinding or cutting instruments is a major cause of patient discomfort. Vibrations produced by instruments that are out of round or inaccurately chucked are of low frequency and high amplitude and produce jarring shocks. These instruments are difficult to control and generally cut a greater area than is intended. A true-running instrument cuts accurately and produces vibrations which are higher in frequency and lower in amplitude (intensity). Improvements in methods of manufacture, quality and design of rotating instruments and chucking mechanisms, closer (and more expensive) tolerances in the fabrication of shanks and more symmetrical shaping of the cutting heads of burs and abrasive instruments should remove much of the annoying low frequency chatter and vibration present in all the speed ranges. The newer concepts of handpiece design and precision manufacture and assembly of the ultra speed handpieces have begun to approach the desired ultimate.

VIBRATION AND PATIENT RESPONSE

The factor of adverse patient response to operative dental procedures is a continuing problem. The cutting or grinding of hard tooth structure is an annoying procedure. Vibrations which are transmitted to the hearing mechanism through bone conduction are most disturbing, even though a local anesthetic may be in effect. Low rotational speeds combined with the heavy pressures necessary in order to remove tooth structure effectively produce vibrations throughout the bones of the skull which are quite high in intensity. Burs produce the lowest frequency and the highest amplitude of vibrations at any one load and speed. Abrasive instruments, on the other hand, having multiple grinding points, produce vibrations higher in frequency than those

produced by a bur revolving at the same speed. Since grinding enamel is more effective than milling, and less pressure is required to cut effectively, the amplitude of vibrations is decreased proportionately. As rotational speeds increase, vibrations are higher in frequency and lower in intensity. These vibrations are in turn less annoying to the patient by virtue of a reduction in sensations due to stimulation of nerve endings in the pulp and periodontal membrane, and by reduction of the intensity of auditory stimuli transmitted through the skull to the hearing mechanism and vestibular apparatus. The ultrasonic handpiece, at 29,000 cycles per second, produces vibrations which are well above the threshold of auditory perception; abrasive instruments rotating in the ultra speed range, with their multiple points of contact during a single rotation, will produce vibrations very nearly approaching the ultrasonic range, thus decreasing patient discomfort. Since cutting efficiency improves as speed is increased, the benefits are two-fold: (1) there is less audible bone-conducted noise while cutting, and (2) the time of contact during which vibrations are transmitted through the skull is reduced.

THE ULTRA HIGH SPEEDS

Recent developments in handpiece design have brought about rotational speeds at the instrument of from 80,000 to 250,000 rpm. The instruments have attained a reasonable stage of perfection. Milling cutters (burs) of small diameters, although inefficient, cut enamel very effectively at these ultra speeds. The burs become, in effect, grinders, and remove hard tooth structure by sheer impact of the blades, even at very light handpiece pressures. The momentary but extremely high forces involved apparently crush the enamel, frequently breaking it away from the tooth a slight distance ahead of the actual blade contact. This action produces an irregular surface which requires finishing with suitable hand instruments. Very fine mesh (NBS 230-270) diamond points are also available for finishing certain surfaces of the preparation.

The revolutionary advancements in mechanical instrumentation for the removal of hard tooth structure have produced some conflicting operator reactions, and the entire concept of operative and crown and bridge procedures utilizing rotary cutters and grinders has been altered from that of a few years ago. An example of this confusion occurs in the apparent lack of effective removal of tooth structure reported by some dentists when employing the ultra speed instruments; conversely, uncontrollably fast removal of enamel and dentin with loss of the tactile sense has been reported by other operators.

There are, at the same time, many dentists who report excellent atraumatic removal of tooth structure and a readily controlled procedure with delicate but optimum tactile perception. An analysis of these conflicting reactions indicates that use of these new instruments requires a "re-learning" period on the part of the operator. Those who report inadequate cutting, and those who report uncontrollably fast cutting, need merely to be apprised of the new basic facts of operating at ultra high rotational speeds, and be permitted to practice with the new device.

Procedure

Cutting and grinding instruments rotated by water or air turbine handpieces operate effectively only with minimal pressures. These handpieces do not produce high torque; they stall readily when more than the lightest of pressures are applied. This inherent factor of low torque results in three important benefits: (1) light pressures produce skull vibrations of low intensity, (2) there is great reduction of heat transfer and hydrostatic shock to the pulpal and periodontal tissues, and (3) instrument life is extended indefinitely.

Until the dentist readjusts his touch to the very light pressures necessary for optimum performance of the turbine handpieces, removal of tooth structure with burs and abrasive instruments will not be satisfactory. A light, intermittent brushing contact with the tooth is necessary for maximum effectiveness. After a short period of re-education, most dentists can operate successfully with these devices, greatly reducing patient fatigue, discomfort and trauma. These factors in turn exert an effect upon the operator. He removes tooth structure with minimal pressures which are more easily controlled than those required with the low speed handpieces. The time of contact of the instrument with the tooth is reduced by as much as 75 per cent. There is less physical effort and expenditure of nervous energy required to operate, and thus the dentist is more relaxed and less fatigued. Many dentists are aware of the transmission of tension from the patient to themselves; a comfortable patient produces less stress in the operator.

Ultra speed instrumentation diminishes the tactile sense of cutting to a degree which requires a distinctly different approach in reducing tooth structure. The ultra speed touch is a wiping or brushing contact at *very light* pressures. Some dentists can develop this touch in a few minutes; for others, several hours or longer may be required.

The air turbine instruments cannot be used for polishing, adjusting and trimming dentures, prophylaxis, sandpaper disking or marginal adaptation of gold work. They cannot be used at lower than their

maximal speed. They are not available as straight handpieces, nor can they be used with large rotating cutting or grinding instruments, or with certain types of amalgam vibrators or condensers. These handpieces must be used as adjuncts to the conventional handpiece; both should be available at all times. In the office of the restorative dentist, the ultra speed instrument becomes the primary; the conventional, an auxiliary for specialized use.

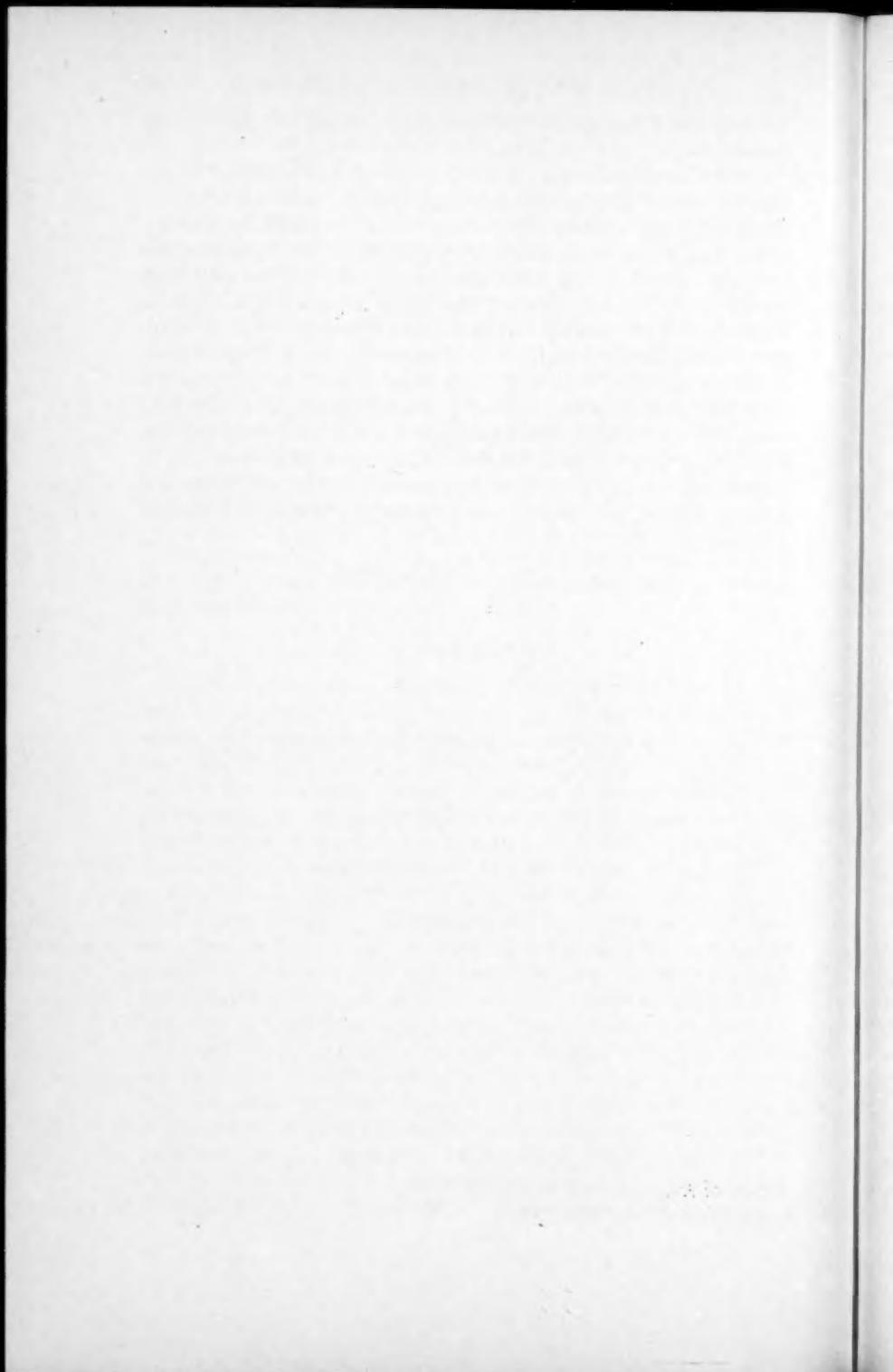
Cavity preparation is in most cases the shortest procedure in a restorative technic. The few minutes or less that are saved in the preparation stage through the use of ultra speed are well spent in planning the procedure. The basic principles of cavity preparation need not be violated by the use of these speeds. They actually permit closer adherence to the classic requirements of sound preparation with fewer steps. In many cases an entire preparation may be accomplished with but one rotary instrument; hand instrumentation then completes the operation. Underextension, a primary cause of recurrence of decay in many instances, frequently occurred with low speeds and ineffective cutting, whereas with ultra speed removal of tooth structure, adequate cavity outline form is achieved with about the same ease as drawing the shape on paper.

SUMMARY

Removal of tooth structure by mechanical instrumentation employing burs and abrasive wheels and points, when utilizing the conventional dental handpiece, is ineffective, traumatic and fatiguing. It is apparent that more efficient operating procedures are possible as a result of the development of rotating cutting instruments of improved design and composition and handpieces capable of speeds in excess of 200,000 rpm. The use of diamond instruments, carbide burs and ultra high speeds provides a more effective method for the rapid removal of hard tooth structures. Through the application of these modern instruments, employing very light pressures and the continuous use of coolants, there is a significant reduction in trauma incident to operative procedures. These are important factors in relieving nervous tension for both the patient and the operator. The vibrations produced by ultra high speed cutting lie in a range of frequencies which approach the upper limit of perception. As a result the sensations produced are less unpleasant than those stimulated by the lower speeds and heavy pressures usually employed. In the final analysis, success in the clinical application of modern instruments is dependent upon the operator's knowledge of the many physiologic and mechanical principles involved. These technics and procedures may change, to some degree, the present concepts of procedures in the removal of tooth structure,

but they do not change the basic and sound principles of classic cavity preparation.

Further improvements in dental handpieces will continue. Speeds that are now considered relatively high may be considered moderate if present trends continue. The design of burs and diamond abrasive instruments in many cases requires improvement. Such factors as the optimum size of the diamond abrasive particles for the ultra high speeds have not been resolved. Bur blade designs which have not changed for half a century may be improved. Perhaps a type of rotary file may lend itself efficiently to ultra high speed cutting. The changes in rotary operating equipment have been so rapid in the past few years that both the profession and the dental industry have been hard pressed to keep abreast of this progress. There is little doubt that the improved devices currently available to the profession have already contributed very significantly toward reducing patient discomfort and operator fatigue, and have increased operating efficiency to a marked degree.



Dental Soldering Procedures

GUNNAR RYGE, D.D.S., M.S.*

Dental soldering procedures have been developed in a rather empirical manner on the basis of soldering and brazing practices used in the jeweler's trade.

Systematic studies of factors which might be expected to influence the strength, dimensional stability and other properties of soldered junctions are few and far between. Coleman,⁵ Turbyfill,⁹ and Stone⁸ have reported strength values for cast solder specimens and soldered wrought wire. Crow⁴ has reported strength values for tin lead solders used in industry, and Weigert¹⁰ has reported data on the strength of soldered junctions using silver brazing alloys. Brumfield² has analyzed the load-carrying capacity of posterior dental bridges and he has emphasized the significance of the strength of the soldered junction. Steinman⁷ has studied warpage produced by soldering, and Fairhurst and Ryge⁵ and Anderson et al.¹ have studied strength and dimensional changes in gold soldered junctions.

The conclusions reached by these investigators are by no means in agreement as far as practical application is concerned, and quite diverging techniques prevail in the dental schools and in dental laboratories and among dental clinicians.

Some maintain that the pieces to be soldered should be in contact, others claim that this will cause warpage. Proponents of one technique advocate that solder be placed in the area to be soldered prior to heating, whereas others prefer adding the solder after the junction is heated to a temperature close to the soldering temperature. Expanding investments are advocated by some, whereas others recommend the use of investments with little or no expansion. Similarly, the treatment of the workpiece after soldering is a matter of disagreement. One school of thought favors quenching the soldered piece, another recommends slow cooling. Also, various methods of heat treatment are advocated after the completion of the soldering procedure.

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The variety of procedures employed in dental offices is illustrated quite well by the fact that one dental gold manufacturer offers twelve different brand name gold solders, varying in fineness from 490 to 809 and with melting ranges from 1300° to 1830° F.⁶ Several of these solders are furnished as rods, rectangles, strips, cubes, or wires, thus reflecting the differences in soldering methods throughout the profession.

In this paper an attempt is made to evaluate some of the manipulative variables mentioned above, with due emphasis on established practices and also on the findings in recent studies.

GENERAL PRINCIPLES

In modern dental procedures solders are primarily used for the joining of cast gold pontics and abutments in crown and bridge work and for the joining of wires and other wrought structures to each other or to prosthetic or orthodontic appliances, including space maintainers. Occasionally solder is also used to build up a contact area, but techniques employing building solders for the forming of lingual or occlusal surfaces have to a great extent been abandoned, and such techniques will therefore not be discussed.

Cleanliness

Cleanliness is the first prerequisite for successful soldering. Not only should the parts to be soldered be free of oxides or contamination from the casting procedure; it is also important that they are not contaminated by polishing agents containing iron oxide (crocus disks), oil, grease, or waxes commonly used in polishing sticks or cakes. If such polishing agents have been used, scrubbing with soap and water followed by pickling in sulfuric acid is indicated (1 part acid *poured into* 1 to 2 parts water). Crowns, bands, and other appliances which have been fitted on fusible metal dies should be boiled in nitric acid (1 part acid, 2 parts water) for 10 seconds to remove traces of die metal before soldering. Sticky wax used for positioning of the parts during transfer from model to soldering investment must be eliminated completely by liberal application of boiling water, since even a thin film of wax may prevent proper distribution of flux and antiflux.

Flux and Antiflux

It is important that the surfaces to be soldered be protected from oxidation during the preheating and soldering procedure. Such protection is most easily obtained by the application of a flux immediately after wax elimination while the workpiece is still warm. If an antiflux

is used, it should be applied in the areas where the flow of solder is not wanted *before* the application of soldering flux.

On surfaces which are not highly polished, marking with a lead pencil will serve as an excellent antiflux. Solder will not flow on to an area which is contaminated with graphite; at extremely high temperature, however, or after prolonged preheating the graphite may burn off. On highly polished surfaces or in cases where prolonged preheating is anticipated a suspension of calcium carbonate (whiting) or iron oxide (rouge) in alcohol will act as an effective antiflux.

Borax is probably the most widely used soldering flux, although it is not well suited for this use. A good soldering flux can be made from dehydrated borax (borax glass), 56 per cent; boric acid, 36 per cent; and silica, 8 per cent. The components should be fused together and then ground into a fine powder; similar fluxes are commercially available. The use of this type of flux prevents the efflorescence which occurs when ordinary borax is heated and it results in a more uniform coating of the surfaces to be soldered, thus facilitating the flow of the solder. The flux can be applied as a powder or, mixed with alcohol (*not* water), as a liquid, but best control is obtained if a paste is used in which petrolatum or a similar organic grease is used as a carrier. Both the parts to be soldered and the solder should be protected by flux before heating, and it is good practice to apply flux again after preheating, immediately before the solder is applied.

Investment

Bridges and prosthetic appliances should be transferred from the master model to a soldering investment of small setting expansion. It is important that the parts to be soldered be held very rigidly together during the transfer and while the investment sets up to avoid distortion at this stage. It is desirable to use an investment which is well controlled by the manufacturer as far as its setting and thermal expansion are concerned. Keep the soldering investment free from contact with water during its setting period to avoid hygroscopic expansion. Do not remove sticky wax or supporting wires until the investment has set up. Following these rules, it is possible to maintain the exact interrelation of abutments, crowns, etc., during the investing procedure. The appliance should be exposed so that there is free access to the solder junctions.

GAP DISTANCE

It has been stated that "the more exact the fit of the parts to be joined, the less will be the distortion produced."⁷ Recent studies,^{1,5}

however, have demonstrated that if the parts to be soldered are in contact before heating, warpage will occur. In the investment soldering procedure, the gaps close up 0.002 to 0.004 inch during preheating to 1100° F. and if the solder gap is narrower than this, warpage occurs.

Figure 1 shows an experiment bridge consisting of three full cast crowns used for control of linear dimensional change and warpage in dental soldering procedures. Connecting gauge rods that parallel the facial and occlusal surfaces at a distance of $\frac{3}{4}$ inch and that have

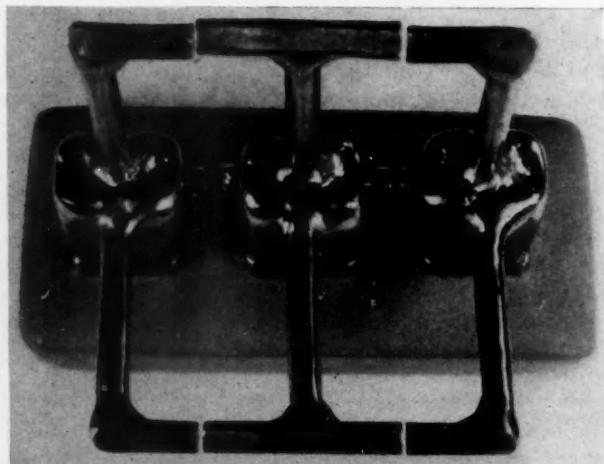


Fig. 1. Experimental bridge assembly with facial and occlusal gauge rods and connector rods. Solder gaps are established between the heads of the cast gold screws located at the contact area.

connector rods to each crown are part of the assembly, which was cast in one piece in a type B gold. Alignment facets were ground on the gauge rods, after which they were cut between the crowns to allow movement of the parts during investment, preheating, and soldering. Imbedded in the occlusal surface of the three crowns at the level of the contact area was a long pencil lead. Threaded holes were made through the crowns at this location and interchangeable gold screws were cast to fit the threaded holes.

Linear dimensional changes of the assembly were measured at the location of the cuts in the gauge rods and in the soldering gaps between the screw heads by means of thickness gauges at various stages of the procedure: on the master model, after transfer to investment, after preheating, at the soldering temperature (without solder), and

after cooling to room temperature. Possible warpage was observed by placing the assembly on a glass plate resting upon the alignment facets at the various stages and the amount of warpage was measured by thickness gauges.

Table 1 shows typical values from heating experiments without the use of solder. It is apparent that the direction of dimensional change depends upon whether or not there is contact at the solder junctions.

TABLE 1. *Dimensional Change Values for Experimental Bridge Assembly During Investing, Heating and Cooling without Solder, for Open and Closed Solder Gaps*

	SOLDER GAPS BETWEEN SCREWS		OCCLUSAL GAUGE ROD GAPS		FACIAL GAUGE ROD GAPS		TOTAL LENGTH OF ASSEMBLY	TOTAL LENGTH OF INVEST- MENT
	R	L	R	L	R	L		
Before investing	0.010	0.010	0.013	0.013	0.013	0.013	1.628	
Before heating	.010	.010	.013	.013	.013	.013	1.628	2.124
At 1100° F.	.008	.008	.008	.009	.011	.012	1.632	2.123
After cooling	.009	.010	.011	.010	.013	.012	1.623	2.114
Before investing	C	C	0.013	0.013	0.013	0.013	1.623	
Before heating	O	O						
At 1100° F.	N	N	.013	.013	.013	.013	1.623	2.086
After cooling	T	T						
	A	A	.016	.020	.012	.014	1.631	2.088
	C	C	.016	.020	.012	.013	1.622	2.079
	T	T						

In the upper part of the table, where a gap was present between the parts to be soldered, we see that all gaps close up a few thousandths of an inch. Upon cooling to room temperature, the gaps opened somewhat even though they generally did not go back to their original opening.

In the lower part of the table, where the solder gaps were closed to contact, we find that the gaps in the occlusal gauge rods opened owing to increase in temperature and remained open after cooling to room temperature; very little difference was noted at the gaps on the facial gauge rod. The values reported were reproducible to ± 0.001 inch for each set of conditions.

Concurrent with these measurements, the over-all length of the bridge assembly and the maximal dimension of the investment were

measured with a micrometer. Typical values from such measurements are also given in this table.

Attempts were made to correlate the resulting values with the coefficients of thermal expansion of the materials involved, but no such correlation appeared to be evident. It is interesting, however, to note that in the several measurements of this nature there always occurred the same over-all contraction of 0.009 to 0.010 inch on both the bridge assembly and the investment when it was cooled from 1100° F. to room temperature, regardless of the gap situation.

About seventy actual solderings were performed on the bridge assembly. The variables studied so far include gap distance and shape

TABLE 2. *Dimensional Change Values for Experimental Bridge Assembly Throughout the Soldering Procedure*

	SOLDER GAPS BETWEEN SCREWS		OCCLUSAL GAUGE ROD GAPS		FACIAL GAUGE ROD GAPS		WARP- AGE	
	R	L	R	L	R	L	R	L
Before investing	0.025	C O	0.013	0.013	0.013	0.013	N O	S L
Before heating	.025	N T	.013	.013	.013	.013	N E	I G
After preheating		A C	.008	.018	.010	.016		H T
After cooling		T	.011	.018	.011	.016		

of the solder gap. Also, some experiments were carried out to study the effect of prolonged heating as well as reheating of the soldered junctions. Only one type of solder has been used for these experiments at this time, namely an 18 karat, 650 fine solder.

Solderings were performed with gap distances of 0.005, 0.025, and 0.039 inch with flat parallel solder surfaces and with V-shaped gaps. Also, solderings were carried out with one or both solder gaps closed to contact.

The dimensional changes were found to follow a pattern similar to that observed when experiments were carried out without the use of solder.

Table 2 shows typical results of soldering the bridge assembly with contact at one of the solder joints and a gap of 0.025 inch at the other. It will be seen that whereas the open gap closed up a few thousandths of an inch during heating and soldering, the closed solder junction

caused dimensional change in the opposite direction so that a slight lengthening of this part of the bridge resulted. In addition, the soldering caused slight warpage when the parts to be soldered were in contact before heating.

The same trends as those observed when the surfaces to be soldered were parallel were found when V-shaped gaps were soldered. If the parts to be soldered were in contact, the gaps in the gauge rods would open and a slight warpage occurred, whereas even gaps as small as 0.005 inch would result in a slight closing of the gauge rod gaps and prevent warpage. When soldered junctions were exposed to prolonged heating either in connection with the actual soldering procedure or in the form of reheating of the soldered junction to the soldering temperature, it was found that the gaps in the gauge rods were closing up as compared to their position after normal soldering procedures.

STRENGTH OF SOLDERED JUNCTIONS

In a study of the tensile strength values of dental gold solder junctions, it was found that no significant difference was caused by variation of the gap distance if the junctions were relatively free of porosity. It was found, however, that porosity occurred much more frequently with small gap distances.

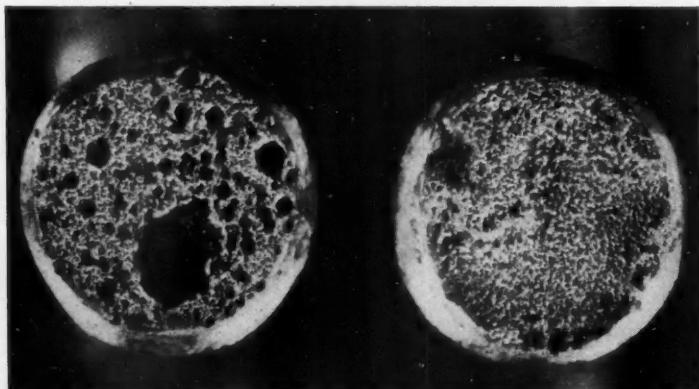


Fig. 2. Solder junctions made under identical conditions except for gap distances which were 0.006 inch and 0.022 inch. Most porosity was found with the small gap distance.

Figure 2 shows the difference in porosity of two soldered junctions made under identical conditions except for gap distance. The porous junction was caused by soldering with a very narrow gap. It was also

found that less porosity resulted when soldering was accomplished by heating the parts to be soldered to soldering temperature before the solder was added than when solder was placed in the junction before heating.

HEATING AND COOLING

Contrary to common belief, a strong solder junction can be obtained without noticeable diffusion between the solder and the parent alloy. In fact, normal dental soldering procedures are carried out at temperatures which do not cause considerable diffusion. Such diffusion requires heating to temperatures close to the melting range of the parent alloy. Figure 3 illustrates the amount of diffusion obtained at various temperatures. At 1400° F., which is just above the melting range of the solder, dendritic structure is evident along the boundary of the solder. At 1500° F. the interface is still distinct. At 1600° F. some penetration along grain boundaries is seen and at 1650° F. there is complete diffusion or alloying of solder and parent alloy. Overheating with resulting diffusion is undesirable particularly when wrought structures are involved, since it results in reduction in strength and ductility. In cast structures, overheating results in grain growth which also causes some reduction in strength and ductility. Also, prolonged and excessive heating results in contraction at the solder junctions as stated above.

Overheating is best avoided by adherence to the general principles of cleanliness and fluxing, in conjunction with proper heat application. It is particularly important to obtain an even and preferably controlled rapid heating of the whole workpiece to a temperature close to the melting range of the solder. This can best be accomplished by pre-heating in a temperature controlled furnace, followed by heating of the whole assembly by a rather large flame before the blowtorch is adjusted to a more localized, pointed cone to be directed toward the individual solder junctions when the solder is applied. Always use the hottest part of the reducing area of the flame, close to the inner, light blue center cone.

Soldering should be accomplished in a few seconds. If the solder does not flow readily, heating should be discontinued and the workpiece should be cooled, recleaned and refluxed before soldering is again attempted.

As a general rule, uniform properties of soldered bridgework are best obtained by leaving the soldered piece to cool slowly in the soldering investment for about 5 minutes before quenching. This procedure will allow gold alloys and solders which respond to an order-

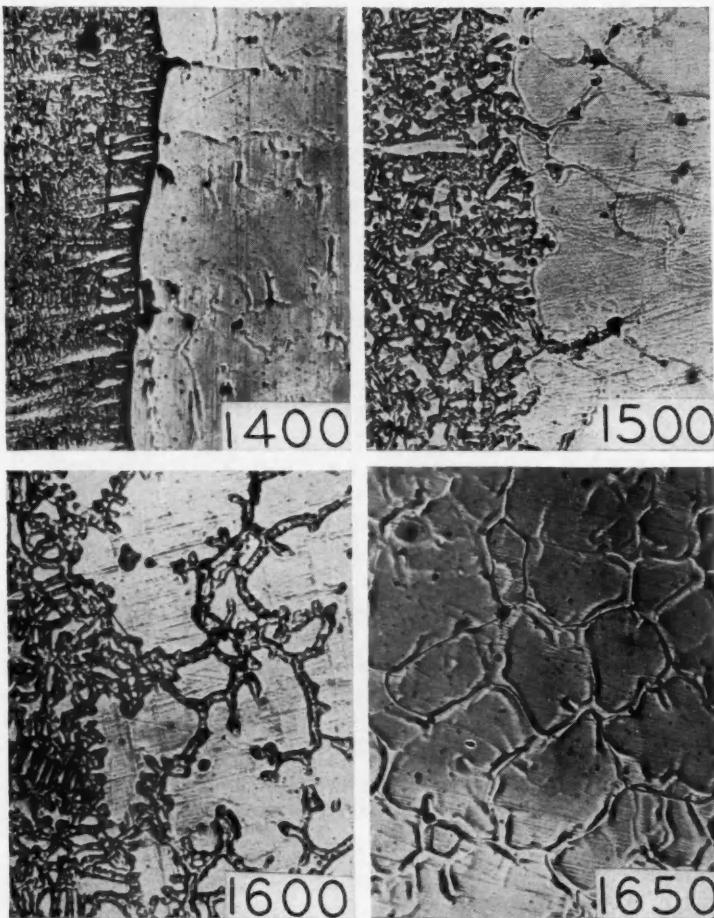


Fig. 3. Diffusion of dental gold solder at various temperatures. At 1400° F. a distinct demarcation is evident. At 1500° F. the interface is still distinct. At 1600° F. there is some penetration of solder along the grain boundaries of the parent alloy, and at 1650° F. we find complete diffusion or alloying of solder and gold alloy.

ing heat treatment to gain some strength and hardness, and it will also reduce the elongation values. Slow cooling to room temperature is not advisable, since it may cause excessive recrystallization and grain growth and result in poor mechanical properties. Some manufacturers of gold alloys and solders give quite specific instructions for the heat treatment of their products, and when such information is

available it is recommended that these suggestions be followed to obtain optimum properties.

CHOICE OF SOLDER

It is common practice to refer to solder by a carat number. The carat number does not indicate the actual carat value of the solder—an 18 carat solder does not contain $18\frac{1}{4}$ gold; the carat number merely indicates that the solder is intended for use with gold alloy of that particular carat. Reputable gold manufacturers indicate the fineness of their solders, and the fineness, in connection with information about melting range and color, is a better criterion for selection of solder for a given job.

As a general rule a solder should have a melting range the upper limit of which is 100° to 150° F. below the lower limit of the melting range of the gold alloy to be soldered. The higher the fineness of the solder, the higher are its melting range and its corrosion resistance. Also, the structure and the response to heat treatment are likely to be more similar to those of gold alloys if a solder of high fineness is chosen. Furthermore, fine solders have better flow characteristics than solders of low fineness, so the use of a fine solder will result in reduced heating time during the actual soldering operation, whereas low fineness solders often have a tendency to ball up. In many instances, they require temperatures considerably higher than their melting range to attain sufficient fluidity.

Solders of high fineness have an additional advantage if the work-piece requires additional solderings or repair; solder of slightly lower melting range can then be selected without having to use solder of so low fineness that there is danger of corrosion and discoloration.

SUMMARY

Gold soldered junctions of high strength can be produced with minimal warpage by adherence to the following principles and procedures:

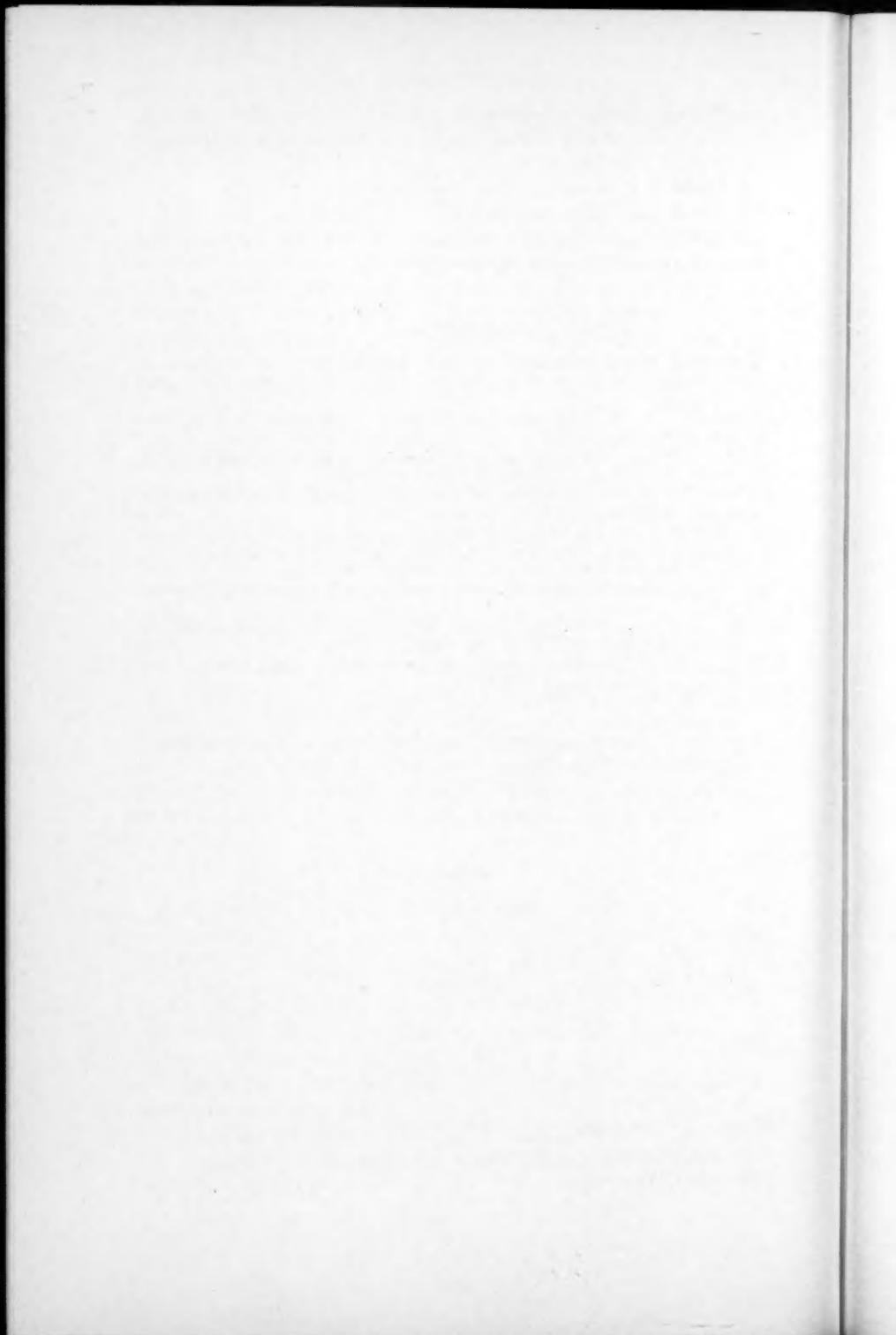
1. Clean the parts to be soldered thoroughly. Remove oxides, dirt, grease, wax, and traces of die metal.
2. Provide sufficient gap distance (approximately 0.005 inch *minimum*) to prevent warpage during heating.
3. Invest in a controlled soldering investment. Do not bury the workpiece in investment.
4. Limit the flow of solder by application of antiflux.
5. Protect the soldering areas from oxidation during heating by application of flux in paste form.

6. Preheat rapidly and efficiently (temperature-controlled furnace).
7. Use solder of high fineness, applied in thin pieces when the junction is ready for soldering.
8. Solder in a few seconds. Avoid prolonged heating.
9. Let the workpiece cool for about 5 minutes before quenching.
10. Pickle by heating in sulfuric acid. Do not heat the metal in a Bunsen flame and plunge it into the acid.

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Cast Chromium-Cobalt Alloys

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Since the chromium-cobalt alloys were first introduced for cast removable partial denture restorations more than twenty years ago, they have become increasingly popular, until now they are used for a large percentage of all cast structures of this type. It was estimated as long ago as 1949⁴ that five times as many removable partial structures were cast of the chromium-cobalt alloys as of gold alloys. Probably the ratio has not been reduced since that time. The reason for the popularity of these alloys for the removable partial prosthesis is not completely clear from the dental literature. Relatively little has been presented to the dental profession to describe the properties of the chromium-cobalt alloys, and few comparisons with gold alloys for similar applications have been made.

Even though the chromium-cobalt alloys are employed extensively for dental appliances, their properties are little understood by the dental profession, and their use continues to be controversial to some degree. The reason for this controversy and lack of understanding is not obvious since the extent of their use in service has continued to increase. Even though both gold and chromium-cobalt appliances have given an apparent degree of success in service, there may be some correlation between characteristic mechanical properties of the alloys and the increased number of removable chromium-cobalt appliances in service. Although the industrial metallurgical literature has described the nature and properties of these alloys for several years, it is only quite recently that the dental literature has contained reports of studies of these same types of alloys for dental applications.^{7-9,11}

As the name implies, the chief ingredients of these alloys are chromium and cobalt, although in some instances the cobalt is partially replaced by nickel.^{6,7} Such alloys are described as "stellite" alloys, and they have not only dental but also wide industrial applications. They were first developed by Elwood Haynes, a pioneer auto-

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mobile manufacturer, in the early 1900's for use where hard, strong, non-tarnishing structures were demanded. They have continued to be used in industrial structures such as airplane jet engine parts that require tarnish resistance and strength at high temperatures. Essentially the same type of stellite alloy is used for dental appliances. It has been noted in the dental literature¹⁰ that the same type of alloy can be used for dental castings, bone surgery applications, and jet propulsion airplane parts subjected to high temperatures, without tarnish, corrosion or loss of strength properties in any of the applications. Actually, much is known about these alloys and their applications, but the interpretation of properties by the dental profession has been neglected to some degree.

The stellite-type alloys should not be confused with stainless steel. The chief ingredient of stainless steel is iron, with smaller quantities of chromium, nickel and other elements which make the steel stainless and tarnish resistant. The chromium-cobalt, or stellite, alloys do not contain significant quantities of iron. Stainless steel is generally used in dentistry in the form of wire, band, sheet or other prefabricated forms, while the stellite alloys are used chiefly as cast structures and are not subject to being shaped by rolling or drawing operations.

It is generally recognized that the first application of these alloys to dentistry was made about 1930 by R. W. Erdle and C. H. Prange of the Austenal Laboratories. At that time they developed a casting technic for dental appliances, using a suitable high-melting stellite alloy cast into an appropriate mold. Following the introduction of Vitallium, several other products were introduced, such as Ticonium, Niranium, Lunorium and Durallium, and a report of the properties of some cast dental alloys appeared in 1943.⁷ Several other products have been described more recently as being available in Great Britain.^{2,6}

NATURE OF ALLOYS AVAILABLE

It has been recognized for a number of years that there is a marked similarity between the composition of certain industrial stellite alloys and those used for dental restorations. This similarity in composition becomes evident from an examination of the values listed in Table 1 for representative stellite alloys. Alloy No. 21 is an industrial stellite alloy which is readily available and is popular for precision casting purposes. It can be observed that there is a remarkably close similarity in composition of alloy No. 21 to alloys B, D, and E, which are available for dental casting purposes. Alloy A shows some variation, in that part of the cobalt has been replaced by nickel and it also con-

tains slightly more molybdenum, manganese and copper than other similar alloys.

As is evident from Table 1, the principal elements present in these alloys are cobalt, chromium, molybdenum and nickel. In most products these four elements constitute more than 95 per cent of the total composition. The remaining elements, such as manganese, copper, tungsten, beryllium, iron, silicon and carbon, act as modifying elements and are present in small percentages for specific purposes.

It is generally thought that the resistance to tarnish of these alloys is due to the presence of chromium, while cobalt is considered to be

TABLE 1. Percentage Composition of Representative Stellite Alloys

ELEMENTS	ALLOYS				
	A	B	D	E	21
Cobalt	43.5	59.4	62.6	61.5	62.6
Chromium	21.6	30.3	26.2	27.6	27.0
Molybdenum	7.0	5.8	5.0	5.3	6.0
Nickel	20.1	1.5	2.3	2.3	2.0
Manganese	3.0	0.34	0.16	0.8	0.6
Copper	3.5	—	.20	—	—
Tungsten	—	0.35	1.2	—	—
Beryllium	0.9	—	—	—	—
Others	0.65	1.25	1.80	2.6	1.8

Data for lettered alloys from Taylor et al., reference 11; data for Stellite No. 21 from *Metals Handbook*, 1948 ed., p. 578.

the element which develops the hardness, strength and rigidity in the stellites. It is thought also that the use of nickel to replace cobalt in the alloy tends to increase the ductility and reduce the strength characteristics. Nickel may contribute also to a reduction in the melting temperature of the alloy. Tungsten continues to be present in small quantities in some products but in many instances it has been replaced by the element molybdenum, which produces improved hardness and strength qualities in the alloy.

Beryllium is thought to contribute to a refined grain size in the alloy, and possibly as a result it produces some increased uniformity in properties. Manganese and silicon are considered to act as de-oxidizing agents in the molten alloy, while the presence of small quantities of carbon to form metallic carbides appears to have a critical effect on the strength of the alloy.

To some extent it appears that the compositions of the existing alloys are somewhat empirical and that further study of the effect of composition on properties would be highly beneficial. An examination

of the existing literature indicates, however, that there is a remarkable similarity in properties of different alloys having a relatively wide variation in composition. Although it is recognized that some qualities of the stellite alloys undoubtedly are influenced greatly by composition, it is generally recognized that considerable variation in properties can result from the use of different casting conditions.¹¹ Such variables as wax burn-out procedure, melting and casting techniques, as well as sprue size and arrangement, probably affect the properties of the finished structure as much as does the composition. Such observations would tend to indicate that further studies of the proper-

TABLE 2. *Mechanical Properties of Representative Stellite Alloys*

PROPERTIES	STELLITE ALLOYS					HARDENED PARTIAL DENTURE GOLD ALLOYS
	A	B	D	E	21	
Yield strength (psi)	64,500	61,000	56,000	62,400	82,300	65,000-90,000
Tensile strength (psi)	108,500	107,500	84,500	102,500	101,300	107,000-120,000
Elongation (%)	3.4	3.2	6.0	1.9	8.2	1.5-8
Modulus of elasticity (psi $\times 10^{-6}$)	28.0	29.5	27.5	28.5	36.0	13-15
Hardness (R [30 N])*	53.0	60.0	51.0	55.0	—	—

Data for lettered alloys from Taylor et al., reference 11; for Stellite No. 21 from *Metals Handbook*, 1948 ed., p. 579; for gold alloys from manufacturers' property charts.

* Rockwell 30N hardness scale.

ties and the influence of manipulative variables in the casting of these alloys is highly desirable.

MECHANICAL PROPERTIES OF REPRESENTATIVE ALLOYS

Recent studies have contributed much to a better understanding of the variations to be expected in mechanical properties of various chromium-cobalt alloys used in dentistry. While further studies are indicated to establish a close correlation between casting conditions and the properties to be expected, it has become evident as a result of recent investigations that there is a similarity in properties of many of the products available.

Some of the mechanical properties are listed in Table 2 for the same alloys whose compositions were described in Table 1. In addition, Table 2 contains some representative values for hardened partial denture gold alloys which have been included for comparative purposes.

Yield Strength

One of the important properties of alloys used for partial denture restorations is that of yield strength. This property is an indication of the stress in pounds per square inch which is necessary to cause permanent deformation of the structure. It is the property which serves to indicate, for example, when a permanent deformation of a clasp will result. A permanent deformation in any part of the structure is an indication that a stress greater than the yield strength has been introduced into that portion of the structure. It can be seen from Table 2 that the values for three of the four dental alloys are in the same order of magnitude. Alloy D is slightly lower in yield strength than the other three. The published value of yield strength for the Industrial Stellite No. 21 is slightly higher than that for the dental alloys. It is possible that this increased yield strength value for Stellite No. 21 is related to the different specimen size which was used for testing this product. Some recent studies have indicated that when Stellite 21 is cast in a manner comparable to dental alloys the yield strength is in the order of 76,000 psi.⁹ It will be observed further from Table 2 that the yield strength for hardened partial denture gold alloys is equal to or greater than that of the chromium-cobalt partial denture alloys. In this respect it is evident that gold and chromium-cobalt partial denture alloys have essentially the same yield strength characteristics.

Tensile Strength

Another important mechanical property used for comparison of alloys is the tensile strength. Again it will be observed that there is a remarkable similarity between three of the four dental chromium-cobalt alloys listed in Table 2, and that the value for Stellite 21 is in the same order of magnitude. Alloy D shows a somewhat lower value for tensile strength than the other products, which may be due to variables in the casting operation, since there is not a pronounced difference in the composition of this alloy in comparison to that of the other chromium-cobalt alloys described. It will be observed also from Table 2 that hardened partial denture gold alloys possess an ultimate tensile strength which is equal to or greater than that of the chromium-cobalt alloys.

Elongation

In a general way the percentage of elongation is some indication of the tendency toward brittleness or the lack of ductility in alloys if the

elongation value is low. The percentage of elongation, therefore, is an important property for use in comparison of casting alloys. It will be observed from Table 2 that there is some variation in the elongation of the chromium-cobalt alloys described for dental purposes. Product E shows an average value of less than 2 per cent while product D shows a value of 6 per cent. This variation probably cannot be related directly to composition of the alloy, but it may be associated with casting and melting conditions. The Stellite 21 alloy is reported to have a value of 8.2 per cent elongation, but recent studies of this alloy cast by dental methods show it to have an average value of 3.1 per cent elongation.⁸ The elongation of hardened partial denture gold alloys seems to cover a range which includes the chromium-cobalt alloys.

Modulus of Elasticity

The value for modulus of elasticity of an alloy is an indication of the degree of rigidity to expect in the structure. The higher the value for modulus of elasticity, the more rigid is the structure expected to be. It can be seen from Table 2 that the chromium-cobalt alloys for dental purposes all show comparable average values for modulus of elasticity. In testing for this property it has been observed that there is some lack of uniformity from one test sample to another in the chromium-cobalt alloys studied.¹¹ Average values, however, show a good degree of correlation, as indicated in Table 2. The value for Stellite 21 is somewhat higher, but this may be related to the size and dimension of the test specimen. It has long been recognized that one of the significant differences between the chromium-cobalt alloys and the partial denture gold alloys is the value for modulus of elasticity. As can be seen from Table 2, the gold alloys have a modulus value approximately one-half that of the chromium-cobalt alloys. This can be interpreted to indicate that the gold alloys are only one-half as rigid as the chromium-type alloy, or, stated conversely, it indicates that the gold alloys are twice as flexible as are the chromium-type cast partial denture alloys.

This property of modulus of elasticity has led to some lack of agreement among members of the profession regarding the merits of either the chromium-type alloy or the gold alloys for partial denture structures. There are those within the profession who advocate the use of a well designed, rigid structure on the basis that it gives better distribution of the forces developed by the structure in service.⁵ Many interesting clinical studies can be related to this property of modulus of elasticity, or rigidity, of the structure. One aspect is that because

of the greater modulus of elasticity, it is possible to design the structure to slightly reduced dimensions, which is of great practical significance. It is now a well established fact that the modulus of elasticity of the chromium-cobalt alloys is approximately twice that of the gold alloys, and no doubt further clinical and laboratory studies will reveal the full significance of this difference in property.

Hardness

The hardness of alloys used for dental restorations is possibly a property of secondary importance from a structural standpoint. The hardness is more likely related to the ease and convenience of polishing, or finishing, the structure, or to the resistance to scratching and abrasion of a restoration which is in service. It can be seen from Table 2 that there is some degree of uniformity in the hardness of the four chromium-cobalt alloys designed for dental purposes. There is no evidence to indicate that small differences in composition are important to the property of hardness. It is interesting to observe that a variety of test methods have been used to study the hardness of both chromium-cobalt casting alloys and the partial denture gold alloys, but relatively few values are available for all products in which the same test method was employed. For example, it is common practice to measure hardness of gold alloys by use of the Brinell hardness test. This method is not appropriate for testing the harder stellite-type alloys, and as a result several different test methods have been employed. While it is possible to make mathematical conversions from one test method to another, the procedure of conversion is not entirely satisfactory. In general, it is recognized that the chromium-cobalt alloys have a hardness number about one-third greater than that of gold alloys, and as a result require high speed rotary finishing instruments to grind and polish this type of structure.

While the extreme hardness of the chromium-cobalt alloys and the resulting need for special polishing and finishing equipment may be considered by some as a disadvantage to their use for partial denture structures, it is recognized that the finishing operation can be completed without difficulty by experienced operators. Furthermore, there has been a trend in recent years to employ the practice of electrolytic polishing for at least a portion of the finishing operation. This method reduces the amount of time and effort required to complete the mechanical finishing operation on the cast structure. Because of their extreme hardness, the chromium-cobalt structures retain their polish well in service.

TYPICAL PHYSICAL CHARACTERISTICS

Color

The color of the chromium-cobalt alloys is a lustrous, silvery white on the finished and polished structure. The partial denture gold alloys generally are various shades of yellow, although silvery white gold alloys are also available. The importance of the property of color in removable partial dentures is not well established; any difference in color is probably of secondary importance.

Density

The unit weight, or density, of the chromium-cobalt alloys in comparison to that of the gold alloys is a property of some importance. This property is particularly significant in bulky maxillary structures where the force of gravity would have an opportunity to be effective, and the weight of the structure could add additional forces to the supporting teeth. The density of the stellite-type alloys averages between 8 and 9 grams per cubic centimeter, whereas many gold alloys have a density of more than twice that amount.

Melting Temperature

The melting temperature of the chromium-cobalt alloys is significantly higher than that of the gold alloys used for partial denture structures. In Table 3 the melting temperatures of various alloys are

TABLE 3. *Melting Temperatures*

ALLOY	TEMPERATURE, °F.
A	2355
B	2605
D	2575
E	2650
21	2547
Gold alloys	1740-1840 (approx.)

Data for lettered alloys from Taylor et al., reference 11; for Stellite No. 21 from *Metals Handbook*, 1948 ed., p. 579; for gold alloys from manufacturers' property charts.

listed in degrees Fahrenheit. It can be seen that there is a close similarity in the melting temperature of alloys B, D, E and No. 21, whereas alloy A is a few hundred degrees lower in melting temperature. It can be seen also that the melting range for dental gold alloys is several hundred degrees below that of the stellite-type alloys.

The melting temperature is important in relation to the technique and equipment that may be necessary for use in melting and casting the different types of alloys. For example, it is well recognized that dental gold alloys may be cast into plaster-bound investment molds and the alloys may be melted by use of gas and air blowtorches. Only alloy A has a melting temperature which is sufficiently low that it can be cast into a plaster-bound investment similar to that used for dental gold alloys. The conventional gas-air blowtorch does not develop a sufficiently high temperature, however, to melt the stellite-type alloys. Because it is necessary to develop high temperatures for melting these alloys, either specially designed electric casting equipment is used, or the alloy is melted with an oxy-acetylene torch. Either method seems to be acceptable in the hands of a skillful operator, but either may damage the alloy if prolonged heating or excessive temperatures are developed during the casting process.

AMERICAN DENTAL ASSOCIATION SPECIFICATION NO. 14

There is now an American Dental Association Specification No. 14 for dental chromium-cobalt casting alloys which became effective July 1, 1957.¹² This specification promises to contribute much to the improvement of this type of dental alloy. One feature of importance is that there is now available a standardized method of testing for physical and mechanical properties of these dental alloys which should contribute to some uniformity of results from one investigation to another. Among other properties, the specification includes yield strength, tensile strength, percentage elongation, hardness and fusion temperature, which have been described in some detail earlier in this report.

INVESTMENT MATERIALS AND CASTING OPERATIONS

In preparation for the investing and casting operation a suitable model of refractory material serves as the basis of the structure to be cast. When the wax pattern is completed on the refractory model, it is invested in an appropriate investment material. If gold alloys are used, the conventional plaster-bound silica investment is acceptable. So far as is known, only one chromium-cobalt type alloy has a sufficiently low melting temperature to be cast into the plaster-silica type of investment mold. For the higher melting stellite alloys it is necessary to use a quartz powder which is held together with an ethyl silicate or a sodium silicate binder to give a suitable mold for the high melting alloy. Other investments are available which make use of a

metallic oxide powder such as magnesium oxide, held together with a phosphate-type binder. When this mass is heated, previous to the casting operation, a complex phosphate is produced which is not destroyed during the time that the high-melting metal is in the mold.

Certain problems may be encountered in connection with casting the stellite-type alloys into molds designed to accommodate the necessary high temperatures. One of the problems sometimes encountered is that of trapping gases in the mold during the cast process. To have suitable strength characteristics and resistance to thermal shock, some of the investment materials designed for the stellite-type alloys



Fig. 1. Defective casting due to gas inclusion.

appear to lack porosity sufficient for the rapid escape of gases, and as a result the gases may be trapped in the mold cavity. The effect of such trapped gases is dramatically illustrated in Figure 1, which represents an incomplete casting being formed in the saddle area of the structure. By skillfully spruing and venting the casting mold, and with complete elimination of the wax residue, these defective castings can be avoided. Various methods of overcoming this problem have been suggested, including the venting of the mold to the surface for the rapid elimination of gases.² Such a method is employed in the casting of test bars for specification test procedures.¹² Similar difficulties are sometimes encountered in the casting of gold alloys into certain dense investment molds, for which reason it should not be

thought that this problem is peculiar to the stellite-type alloys and molds.

Since the stellite type alloys have a casting shrinkage in the order of 2.3 per cent,³ it is necessary that the mold be expanded more than when casting gold alloys, which have a casting shrinkage in the order of 1.5 per cent. The mold expansion for the chromium-cobalt type is accomplished primarily through thermal expansion methods. Adequate expansion can be attained in the mold and structures can be cast which display adequate compensation and fit characteristics. Possibly further investigation is indicated in this area to determine the method of proper control of expansion in the investment mold for the stellite-type alloys.

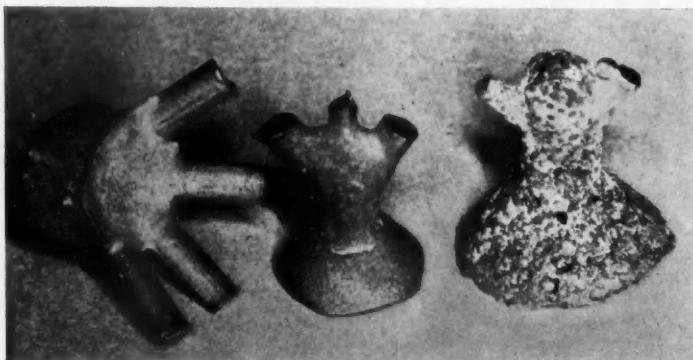


Fig. 2. Sprue buttons representing damage by improper heating.

During the melting and casting process, severe damage to the alloy can result if the melting operation is not skillfully and carefully controlled. In Figure 2 may be seen three sprue buttons from different castings which represent different degrees of damage to the alloy during the melting process. The button on the right shows excessive porosity and severe contamination with the investment mold material. This would probably indicate that the metal was excessively heated and the resulting casting would have inferior properties. The sprue button in the center shows only minor irregularities on the surface; probably the casting from this melt of metal would be acceptable for service even though there is some evidence of slight damage resulting from the melting operation. The sprue button on the left illustrates well melted alloy free from porosity or other damage and shows fine detail registered in the surface of the metal where it was in contact with the investment mold. As indicated earlier in this report, it is

probable that such factors as these indicated here are of more importance in controlling the properties of the finished structure than are the variations in composition between different alloys which are available.

In Figure 3 are two typical structures in the finished or semi-finished condition which illustrate the use of chromium-cobalt alloys in dentistry. These structures, initially formed in the cast state to produce a skeleton structure with appropriate clasps, are finished by attaching suitable denture base material and teeth in the proper



Fig. 3. Cast partial denture appliances.

relationship. Much clinical study is given to the choice of clasp materials and the proper design of the structure to give stability and support, both for the remaining teeth and for the appliance. The mechanics related to design of such partial denture structures are of paramount importance and represent an important aspect of clinical procedures.^{1,5,6}

SUMMARY

The chromium-cobalt castings represent an important group of alloys in the field of partial denture prosthesis. In recent years the properties of these alloys and the related investment materials and casting techniques have come to be better understood. An American Dental Association Specification is now available for this type of alloy and

further studies of mechanical and physical properties of cast structures will undoubtedly result in improved practices and restorations. It is to be anticipated that further studies will be reported in the dental literature and that as a result refinements and improvements will continue to be made available. At the present time there is good indication that the chromium-cobalt alloys are rendering a useful service in dentistry and that, if proper attention is given to the technique of design and casting, a very serviceable restoration can result.

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Stainless Steels in Dentistry and Orthodontics

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A quarter of a century of clinical usage with increased acceptance each year is justification for consideration of stainless steel along with the other recognized dental materials.⁵ In sharp contrast to the industrial field, it has not been well laboratory tested in dentistry, and as a result, clearly defined specifications for use are still lacking. There is a definite need in our profession for the material to be produced and marketed in a manner similar to that established in the gold industries.

The increased use of stainless steel in dentistry has been largely for elective reasons in the United States, because we are almost the only country that has had enough excellent gold products available. Its original main selling point of much lower unit cost has been neutralized by the rising costs of other things which affect the fixed overhead of professional offices. When it is employed in a dental or orthodontic case according to the standards of metals of the gold group, it is apt to require as much time and perhaps superior skill. Its advantage must be on a performance basis to justify use.

The growth of stainless steel in dental fields might be compared to that of dental amalgams in that the original material was probably not of suitable quality and was degraded in many ways. Existing manipulative techniques were unsatisfactory and new ones had to be perfected. In some instances, it was vigorously rejected by leaders in the profession and was given no (or unfavorable) attention in the literature and teaching institutions. Originally, the stainless steel groups had to gain converts wherever they could and sell their merchandise in the face of highly competitive situations. The "soldering" of the material presented challenges and new brazing techniques were developed. Also, convincing the profession as to the merits of resistance welding has been a slow and arduous process. The development of

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new instruments in some instances was necessary to manipulate the material properly.

COMPOSITION AND MANUFACTURE

Stainless steels are composed of iron and carbon in proper ratio, plus elements which make them corrosion resistant, plus additional elements which discourage the carbon from uniting chemically with iron and chromium. They do not lend themselves, as yet, to casting procedures, and should not be confused with the chromium-cobalt alloys which are discussed by Dr. Floyd Peyton in the preceding article in this symposium. Stainless steels, therefore, can only be competitive with a casting technique if a special design, capable of being fabricated by a brazing or welding procedure, will do the job as well or better. An example of this would be a space maintainer which may be all cast gold or made with stainless steel bands joined by a stainless steel wire.

In the production of stainless steel, the cleaning during and after rolling is a most important factor. The trapping of carbon particles on a surface can be the source of a carbide corrosive action. When it is used for an intraoral application one should discard material with black specks on the surface. This carbide corrosion is a reasonable explanation for localized but complete disintegration of an arch bar or wire which has been in the mouth for some time.

Strangely enough, metallurgists are not positive as to why the metal is stainless. The most likely explanation is that it becomes uniformly coated with an invisible oxide, which is referred to as the "passive film." An optimal surface on stainless steel is produced by careful rolling and meticulous cleaning during and after processing. Its reflective surface can be disturbed by high heat, poor oral hygiene in some mouths over a long period of time, abrasives, and caustic reagents. It must be borne in mind, therefore, that the metal stays stainless and bright under reasonable circumstances but can be affected if certain principles and conditions are violated.

The general classification of these metals consists of three groups:

1. *The martensitic group* is composed of iron, 0.09 to 1.20 per cent carbon and 12 to 18 per cent chromium. Within reasonable limits members of this group respond to heat treatment procedures and their most common use in dentistry is in the production of instruments. They resist tarnish quite well, but their hardness is not as great as that of tool steels. Recently, manufacturers have learned to insert or add carbaloy bits and tips to compensate for the softness and make possible a very hard cutting edge on chisels and pliers.

2. *The ferritic group* is made up of iron, 0.05 per cent or less of carbon, and 15 to 28 per cent chromium. These steels, too, respond favorably to heat treatment within reasonable limits. Their application is limited in dentistry to the manufacture of parts for equipment where reasonable corrosion resistance is desired but where the machining qualities of conventional steels are desirable.

3. *The austenitic group* is composed of iron, 0.01 to 2.00 per cent carbon, 15 to 25 per cent chromium, 8 to 20 per cent nickel, as well as trace elements of tantalum, titanium, columbium, zirconium, manganese, molybdenum, phosphorus, silicon and sulfur. Some of these metals are added to stabilize the chromium and iron in solution and reduce the tendency to form carbides of these elements in the face of heat. An alloy of iron that is very low in carbon and contains 18 per cent chromium and 8 per cent nickel plus a trace of stabilizing elements is commonly referred to as "18-8 stabilized."

The stainless steels in the austenitic group are listed as specific combinations and designated by numbers from 302 to 306 in publications such as *The Metals Handbook* of the American Society of Metals. From this group come most of the strips, sheets, and wires used in dentistry and its allied fields, especially orthodontic material. Although austenitic steels have very good corrosion resistance, yield strength, tensile strength, hardness and toughness, small sizes of wire are apt to demonstrate these qualities with considerable variation.

In order to deliver to the ultimate consumer, such as the dentist, a sheet or wire suitable for intraoral usage, the manufacturer must employ careful and clean procedures. The trapping of foreign material during the rolling steps could result in major defects in thin-gauge end products. Such inclusions can cause failure because of mechanical weakness, i.e., unduly soft or hard areas as well as actual metallic voids, or they can be the site of corrosive action because of the affinity of the stainless steel elements under conditions encountered in intra-oral use. In addition to mechanical cleaning procedures during production, therefore, it is imperative that stainless steel be cleaned chemically with warm nitric acid to remove any substance other than the necessary ingredients.

THE APPLICATIONS OF THIN-GAUGE STAINLESS STEELS

The pedodontic and orthodontic fields in particular have benefited by the pre-forming of 0.004 to 0.008 inch stainless steels into bands and crowns as shown in Figure 1. This is possible because of the effectiveness of annealing, which alters yield strength and tensile strength and reduces hardness, thus facilitating die forming. Since the

material readily strain-hardens, the end product has the edge strength necessary for good performance, although it may be more difficult to adapt than a gold alloy.

The very thin stainless steels, known in the commercial field as "shim stock," have been used longest in dentistry as strips for matrix bands. They have been used for orthodontic banding for over twenty-five years, but until recently have been difficult to form to high standards. To offset this handicap, preformed seamless ferrule bands were developed in multiple sizes which worked very well on central and

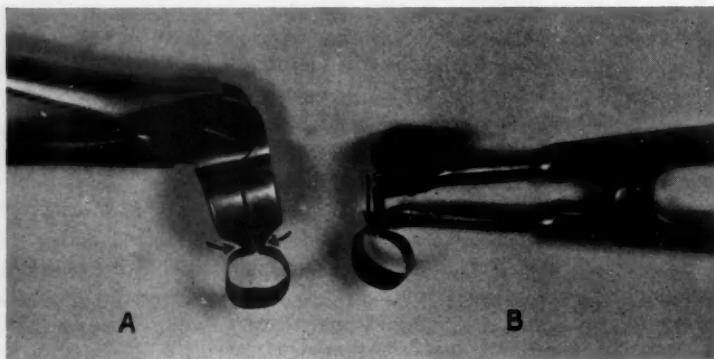


Fig. 1. Two efficient band-forming pliers for bicuspids and molars. On the right is the popular S. S. White-Angle instrument with concave forming beak. On the left is the Rocky Mountain Metal Products Company's band former; made according to a design suggested by Dr. J. D. Peak, of Texas, it seems to have improved mechanical advantages for "pulling up" stainless steel bands.

lateral incisors and first permanent molars, but not so well on the other teeth, especially typical tooth forms.

It remained for Dr. J. D. Peak to suggest a design for a new type of band-forming pliers that has been developed through the resources of Rocky Mountain Metal Products Company. Although there are weaknesses in the instrument, because of its bulk and angle of application, it seems to offer the mechanical advantage required to pull up semi-preformed bands (Figure 2A, B, C and G). It is shown in Figure 1A with the popular S. S. White-Angle band former with concave forming beak for bicuspids and molars as suggested by Dr. W. B. Downs. Note that in the Peak pliers on the left, the tail of the band is firmly held with a "keyed vise" principle instead of a screw clamp which can slip in a tight adaptation. Friction and shearing are minimized by getting away from the sliding-split forming beak, on which the band material must make a 90 degree turn. Both beaks of the

Peak instrument are involved in stretching and forming simultaneously so that its efficiency will tax the superb strength factors of the stainless steel with only a reasonable risk of shearing.

Stainless steel banding materials have ample strength and hardness and can be used in thicknesses 0.001 to 0.003 inch less than gold alloys. Figure 2A shows a 0.003 inch cupid strip, B is a 0.005 inch lower molar band and C is a 0.004 inch bicuspid made by Williams according to the Whitman design. Figure 2G is a 0.004 by 0.125 inch soft band strip marketed by Unitek, to which is welded a tough

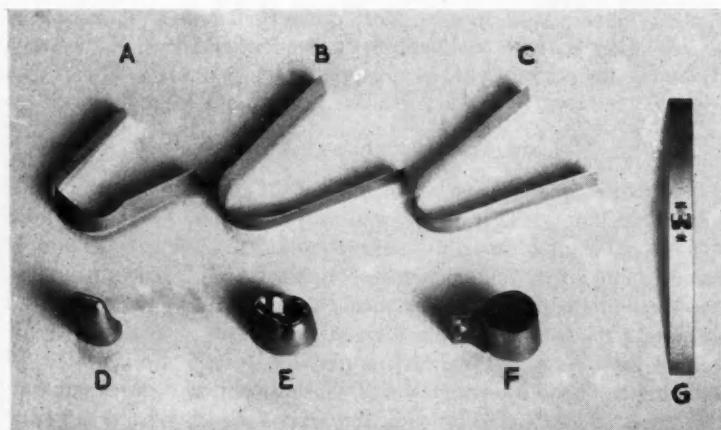


Fig. 2. Semi-preformed stainless steel aids to dentistry and orthodontics. A, B, C, Three bands made up for the author by the Williams Company. D, E, Stainless steel crowns and (F) the Curry matrix, made for the profession by the Rocky Mountain Products Company. G, A new band made by the Unitek Company according to a design suggested by Dr. Steiner.

edgewise arch bracket and a hard rotating spring. Rocky Mountain Metal Products Company has a Curry matrix with a very soft 0.002 inch strip that is backed up with a 0.010 inch cleat which, when pressed together with pliers after placement, produces a good cervical fit (Fig. 2F). Figure 2D and E are samples of the popular preformed stainless steel crowns.

The semi-preformed stainless steel band blanks made according to the forms suggested by Downs, Whitman and others and adapted with modified Peak pliers can produce results equal to and, in some cases, superior to wrought gold as to general retention and marginal adaptation. The technique may prove more difficult to master, but is more desirable in most cases than are adapted preformed bands. It is more self cleansing than other materials although claims as to

caries reduction are not substantiated by scientific investigation. Thinner gauges than those available in gold alloys offer ample edge strength and other hardness advantages without encountering brittleness. The decreased bulk of band material minimizes separation problems and facilitates cementation.¹¹

Thin-gauge materials are best bonded by spot welding rather than soldering. Stainless steel is responsive to this process because it offers ample resistance to the flow of electricity and melts in small spots which are in turn pushed together by the pressure on the machine electrodes. The principal suppliers of stainless steel specialties for dentistry have played an important part in perfecting equipment that is correct as to time, temperature and pressure required to bring about excellent spot welds on materials such as we have been discussing.

SOLDERING OF STAINLESS STEELS

It has been implied that stainless steel differs in one respect from golds in that it lends itself to welding procedures. Although it can be bonded in an open flame with intermediate metals, this bond is normally not a true soldered union;²⁰ brazing would be a more accurate term in that it suggests a mechanical bonding with intermediate metal rather than a chemico-physical union.

Since most American technicians have graduated to stainless steel soldering from the use of gold, it is well to mention a few important differences in the two techniques. If stainless steel is heated to 1400° F., one is encroaching on the annealing range of the metal and it is difficult to salvage the original physical properties by any practical means, so an onset of softness is noted. At considerably higher temperatures, say above 2000° F., the elements in the stainless solution become disarranged and as a result the wire is permanently ruined. We can say, then, that the soldering range (i.e., the difference between the melting point of the solder and the point of damage to the wire) is narrower than in the gold alloys.

The fluxes used on stainless steels can be used on gold, but the reverse is not true, because gold fluxes may have a petroleum vehicle that on fusing invites carbide formation. As a result water is used to make the paste and it requires remixing to stay a creamy consistency. Gold fluxes contain no reagent such as potassium fluoride that will chemically clean the steel. A good flux for stainless steel soldering would be, in dry form, potassium fluoride 50 per cent, boric acid 34 per cent, borax glass 8 per cent and sodium silicate 8 per cent. The generous use of the flux with proper heat, cleanliness and apposition, helps to keep the copper and zinc from freeing themselves from the

other solder elements, and hence penetrate the crystalline structure of the stainless steel, reducing ductility in the solder joint area.¹⁹

Although the flux is important in the soldering of gold, an acceptable joint can be made by a clever operator using high grade materials under favorable conditions. In soldering stainless steels, a generous amount of a fluoride flux is imperative (1) to clean and break through the passive film of the stainless steel, (2) to guard the lower-fusing metals in the solder mixture against oxidation, (3) to help clean the metal being joined to the stainless steel, (4) to aid in the uniform distribution of heat throughout the region of soldering, and (5) to form a glass bead which congeals before the solder hardens completely. It is necessary to crack away the glass bead formed and it is important that no corrosive fluoride product remain to start further chemical action in the presence of a warm saliva medium. Mechanically cleaning the area with pumice or placing it in warm nitric acid may be necessary to insure cleanliness.

A butt joint is a common way of joining two gold wires with a minimum of solder, and it may have ample strength and retention. However, in stainless steel soldering, one must make sure that the soldering material wraps around the wires so that the weak solder has enough mass to hold on. Furthermore, the edges of the solder ought to be nicely feathered onto the steel so that no crack is left for agents to enter and start a corrosive action.

Stainless steels can be brazed with low carat gold solder but they seem to offer no advantages over silver solders, which are usually about 52 per cent silver, 22 per cent copper, 18 per cent zinc and 8 per cent cadmium. They usually will melt between 1100° and 1200° F., which puts them near the lower end of the annealing range of the steel. To reduce the risk of overheating the stainless steel it is common practice not to put it in the flame but rather to draw in the heat on the wire being soldered to it, and give the flux an opportunity to distribute the heat in the solder area. Heat control, therefore, becomes even more important than in gold soldering and for this reason, soldering together material on models is challenging. The natural tendency is to burn one member before the other is hot enough to receive the solder.

HEAT TREATMENT OF STAINLESS STEEL WIRES

Heat treating is the raising of the temperature of a metal for varying periods of time and then cooling it rapidly or slowly with the intention of altering physical properties so that it will function better for the purpose intended. There are many ways in which one might

classify the effects of heat treating, but generally members of our profession are interested in (1) relieving stress retained from the spotty effect of cold working, or "tempering" internal strains; (2) hardening the wire throughout; or (3) annealing to remove brittleness by bringing about a general softening and raising ductility.

When we speak of stainless steel we are not referring to a specific alloy but to the Nos. 302 to 306 austenitic group and to a more recent material called Elgiloy, which is 40 per cent cobalt, 20 per cent chromium, 15 per cent nickel, 7 per cent molybdenum, 2 per cent manganese, 15 per cent carbon and 0.04 per cent beryllium.⁸ Unless manufacturers market their material with advertised variation in physical properties, in general the metal has been heated and cooled



Fig. 3. Three electric heat-treating devices suitable for office use. On the left is an electric oven with good temperature control features. In the middle is an inexpensive heater marketed by the Baker Company; if used as described in the text, it produces very satisfactory results. On the right is the Elgiloy attachment for the Rocky Mountain welder, which induces heat in an arch wire by electrical resistance and requires a "flash paste" to indicate temperature.

to homogenize stress so as to afford the best possible combinations of ductility and strength.¹³ The doctor who is putting the wire through a heat-treating process usually wants to make it more resilient or improve the elastic qualities while actually striving to increase hardness, tensile strength and proportional limit.

In Figure 3 are shown three electrical devices suitable for routine heating of stainless steels. On the left is a well insulated oven with a sensitive pyrometer and a rheostatic control. The heating element wires are concealed so that electrocution is impossible. Because of its slow response it must be in almost continuous operation during clinical hours to be available for use.

The device shown in the middle of Figure 3 is an electric base heater that has a perforated mica floor and a Pyrex cover. When plugged in it operates at a heat of about 950° F. with reasonable fluctuation in temperature. To vary effects in its use one must alter the time factor, but normally it is thought of as a three minute process

for stainless steel. For best results the wire being heated should be elevated on a tripod frame so that it will not burn from excessive heat coming up through the mica perforations. The instruments should be standardized before using on an actual case because of variations in power source and possible differences in heating elements.

On the right in Figure 3 is the type of heater suggested for Elgiloy, in which heat is generated within the arch wire because of resistance to the flow of electricity. At the mid-point of the arch can be seen a black dot, which is a paste that will flash when the heat at that point reaches about 700° F. This equipment cannot heat a wire uniformly throughout, and differences in results are noted as arch length, size and form are changed. Its principal advantage is convenience in that auxiliary help can process an arch readily. Items other than arches such as bands, space maintainers, clasps, retainer wires must be heat treated by other means.

Not shown is another procedure that might become more commonly used in the future. With practice, and under proper lighting conditions, one can get quite acceptable results by heating the metal in a brush flame to the lowest visible red as prescribed in Howe's color scale. On cooling, the stainless steel will be dark straw color that cleans up nicely by means discussed below in the section on cleaning, polishing and reducing.

The utilization of these processes for best results is immediately complicated by three variables: (1) Physical properties of stainless steel wires will vary to some degree on a size basis alone. (2) The unknown chemical composition of the wire in some cases complicates the working out of a procedure based on the reaction of elements of the alloy. (3) The variation in production procedures, even though chemical composition is uniform, can alter physical properties markedly. Until a satisfactory level of quality control is reached we can only warn users that repeated checking of the heat treatment procedure, according to one source of supply, type of equipment and kind of application, may be necessary.

Since the variables mentioned above are apt to be present it is recommended that a quality electric furnace as shown in Figure 3 be used so that accurate heats are uniformly available in working out a heat treating technique. In the majority of applications the operator will do well to start with wire which was manufactured to a medium range between hard and soft. Thin-gauge sheet such as band material should be bought in its soft state, since in handling it will work harden readily.

Considerable difference of opinion exists among competent investigators as to what are the effects of heat treatment of stainless steel

and what procedure is the most effective. It is felt at this stage of our knowledge that a temperature of 850° F. for 8 minutes should be suggested for most uses, with a fluctuation towards 950° F. for 3 minutes on the one hand and 750° F. for 20 minutes on the other. The trend among industrial metallurgists is to recommend longer times for adjustment of internal structure. The manufacturers of Elgiloy recently advocated 950° F. for 60 minutes for optimum results.

In the section on soldering it was pointed out that heats above 1200° F. are near the lower end of the annealing range and that care should be taken not to soften the wire, because heat treating procedures now in use are incapable of restoring physical properties. Warpage of arches, especially the more complex and heavier types, is apt to occur under heating and they should be rechecked for accuracy before insertion.

Although findings are not uniform, we feel confident in saying that heating at a temperature of 850° F. for 8 minutes should improve the ability of a wire form such as an arch to resist permanent deformation.² In office tests this heat and time ratio seems to relieve stress in clasps, labial wires and spring loops to a degree that decreases the chance of breakage. The performance of office-made coil springs may be improved by similar treatment.

One should bear in mind that heat treating of stainless steel for uses in dentistry has been going on for only about ten years and most of the work has been done since 1951. Except for the phases of annealing we have had difficulty in transposing the work of industrial metallurgists because the physical properties of the metal vary with size and shape. Furthermore, oral use of stainless steel raises chemical and physical problems that seem to be more challenging to solve. However, the trend in recent years would indicate that the energetic combined efforts of industrial and professional investigators could bring about a solution to most of the big problems within the next decade.

CLEANING, POLISHING AND REDUCING

Cleaning and Polishing

Since stainless steels are tarnished by soldering, heat treating and exposure to corrosive reagents, it is important to know how they can be prepared for use in the mouth. The pickling phase was mentioned as an important step in production, and placing the fabricated appliance in warmed nitric acid will effectively clean off all foreign material but will leave a gray satin-like surface because of lack of polish. The

use of pumice and a lathe brush is also effective if the shape or form is such that all parts of the surface can be reached. This too will probably leave a dull cleaned surface, and even finer polishing materials may prove to be ineffective in restoring lustre.

When the clean dull surface occurs during production cleaning, it is restored to brightness by the compressive action of rolling or forcing through reducing dies. Since burnishing action is impractical at the clinical level, the profession has been aided by the anodic polisher shown in Figure 4. Its action is essentially the reverse of a plating pro-



Fig. 4

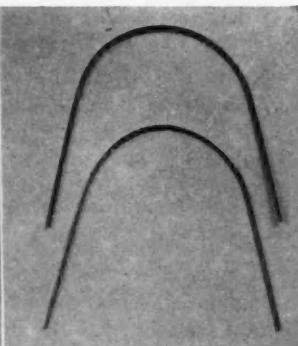


Fig. 5

Fig. 4. The electronic Passivator for polishing and reducing stainless steels and chromium-cobalt alloys. Its use is described in the text.

Fig. 5. Two 0.030 inch 18-8 stabilized stainless steel arches. The top one has been heat treated for 8 minutes at 900° F. The bottom arch has been heat treated and electronically polished in 15 seconds in the machine shown in Figure 4.

cedure in that it removes the passive film and the metallic salts, leaving only the parent alloy with its original brightness within a period of 10 to 15 seconds.

The part to be cleaned is placed in the clip on the end of the arm that is in turn clamped in the pole in the center of the top. It is then completely immersed in the phosphoric acid in the perforated porcelain dish. When the machine is energized, by turning on the timer switch, the current flows up the pole, across the arm, through the stainless steel being cleaned, into the acid bath and out through the metallic pan, which is actually containing the acid, and into the machine circuit. The current will remove from the metal being cleaned an immeasurable amount within the recommended time, as can be seen in Figure 5. The other porcelain dish, which has a cover, contains a baking soda solution so that the acid can be quickly neutralized when the process is finished.

An appliance which has been in the mouth for some time will be coated with debris, and it should be mechanically cleaned before being placed in the anodic polisher. The toggle switch permits selection of two levels of current to adjust to rate of action and, to some extent, to effectiveness of action.

Reducing

If a reduction in size is desired, the anodic polisher, or "Passivator," is the equipment to be used, because it will remove metallic salts first, and then the metal itself equally on all surfaces at the rate of about 0.001 inch per minute. If a 0.0215 by 0.0275 inch rectangular arch is placed in the operating machine it will be reduced and polished to 0.020 by 0.026 inch in about one and a half minutes. Similarly, a round, square or rectangular wire that is too large to fit a tube can be reduced to any desired tightness or looseness. A 0.007 inch band or crown can be reduced to any thinness required without changing form.

Since the metal must be immersed in the phosphoric acid to be acted upon, it is possible to reduce wires or strips in various parts of an appliance, such as the anterior or buccal portions of an arch, rather than all surfaces. It is also possible to control the areas to be reduced by coating with wax those parts that one does not wish to have affected. The anodic polisher and reducer has already played an important part in making stainless steels and the chromium-cobalt alloys more useful to dentistry and orthodontia.

SPECIAL APPLICATION OF SMALL STAINLESS STEEL WIRES

Within recent years the dental profession has found increased use for small wires in surgical and periodontal as well as orthodontic techniques. If these wires are bright and are annealed to a soft state they are called ligatures. If on the other hand they have been hardened to a degree just short of brittleness they are called finger-spring materials. The majority of these wires are about 0.010 inch in diameter, but they may be employed in larger or smaller sizes according to needs.

The use of ligature-locking pliers is strongly recommended when using soft stainless steel in order to take full advantage of the material's tensile strength without shearing and to facilitate the making of a neat knot before work hardening makes it brittle. This material in the 0.015 inch size range has enjoyed acceptance in surgery for bone wiring and fracture management because of its compatibility

with the body fluids and tissues. It does not have a high luster because maximum softness is desired, so after being annealed at about 2000° F. it is pickled in warm nitric acid and not reworked against rolls or dies.

A wire which was quite popular in this country before World War II came from Europe under the trade name WIPLA which, when translated, suggests "like platinum." During this period German instrument makers developed and produced ingenious pliers that aided in cold forming the wire into intricate designs with a desirable amount of work hardening.

A practical way to make a coil spring is to wind a 0.010 inch soft Elgiloy or 18-8 austenitic wire around a 0.030 inch hard wire, heat treat at 900° F. for eight minutes, and polish in the Passivator shown in Figure 4 for 15 to 30 seconds. The mechanical polishing of stainless steel springs with a brush and pumice or a motor-driven wire brush can work harden the metal to the stage of brittleness.

Some of these small wires come to the doctor hardened to a spring degree by the compression of the last die drawing, rather than from work hardening or heat treatment. Fine spring stainless wires are particularly sensitive to too much heat irrespective of how the hardness is induced. The critical range between desirable hardness and the annealed state is a time-temperature phase of soldering and welding that requires attention to detail. For this reason many clinicians attempt to work out designs in which springs are used in such a way that they do not require welding or soldering.

SUMMARY

It should be considered a milestone of progress that stainless steel materials and techniques are included with the modern dental materials. Justification is based on the fact that stainless steel has been employed for at least twenty-five years, with increased acceptance each year. Although much progress was made on a trial and error basis, the last ten years have seen an approach to its problems in a truly scientific manner, and it is hoped and assumed that the combined work of industry and the profession can lead to an even higher level of attainment.

The properties of stainless steel render it potentially superior in many applications, but the standards established in gold techniques can be equalled or surpassed only by careful attention to detail, the use of specialized equipment and the mastering of challenging techniques. Because special lines of reasoning, knowledge and procedures are at times in sharp conflict with those employed with other metals,

perhaps one should not attempt to understand and perfect several wrought designs and fabrications at the same time.

The shortcomings of the material, the weakness in production and marketing as well as the faults of operators are alluded to as constructive criticisms in the hope that progress might be stimulated in many directions at the same time. The willingness of the orthodontic groups to shoulder the problem of heat treatment should have occurred many years ago when suggested by the gold producers. The close cooperation between the profession and manufacturers in the development of more effective instruments and improved stainless steel parts that lend themselves to better fabrication have been arduous and costly undertakings but conspicuously progressive. Increased testing in clinics and private offices, perfecting of instruments and materials, the acceptance of welded design as well as some scientific support for contentions of proponents of stainless steel have resulted in that group's being able to shift its thinking from defensive toward offensive. This may be considered as the precursor to accelerated advancement.

There is a definite need for the setting up of standards on specifications for stainless steel, especially for wires that are used in dentistry. It should result from the combined efforts of the profession, its dental material groups, the manufacturers and some representatives of a metallurgical group experienced in quality control of comparable alloys. Such specifications might have to be incrementally revised but they should minimize existing confusion and stimulate scientific investigations.

The professional man should some day be able to place an order for stainless steel and be assured of the following:

1. The dimensions are micrometrically correct.
2. The physical properties of the wire as it comes to him are clearly defined, within reasonable limits, as to hardness, tensile strength, elongation, proportional limit, etc.
3. The performance of the wire in cold manipulation is reasonably clear, i.e., how it will work or strain harden, and how susceptible it is to deformation.
4. The chemical composition is available so that the user comes to know the importance of ingredients and how they can be expected to react under his use. This information is readily available to industry but has tended to be withheld from the profession.

In addition, eventually we must expect reasonably dependable advance information on how each wire should behave when heated for treatment purposes.

One must realize that instituting quality control to these suggested specifications would raise the unit cost of stainless steel wire, but in

our present economy this should not deter us from encouraging such a move.

Until such time as sweeping advancements may come about we can do most commendable work with the materials and equipment we have available. In the past fifteen years the dental profession has gradually learned that silver amalgam, if carefully handled according to prescribed metallurgical and operative principles, can challenge and in many instances surpass the gold inlay. Stainless steel should not be used with separate and lower standards in mind than those of wrought golds but rather with the same or higher standards as an objective.

The lower cost of stainless steel materials and the fact that expensive inventories are not required, which would be subject to theft, are mentioned among its advantages, but other characteristics should be considered as more important. Its color is regarded by the public as more desirable than that of gold. It can be given a high polish quickly with the equipment described. It is noticeably more self cleansing in most mouths, which assists oral hygiene and caries control measures. It is a readily weldable material with equipment now available, and welded design should have much to offer our field in years to come. The wires can be cold formed into any desired form within reason, without fracture. Its strength per unit of mass is great enough to permit thinner bands or crowns and fine wires if desired and still have the ruggedness to resist ordinary abuses. The industry has been co-operative in the development of semi-preformed materials and there is every reason to believe that further progress in this direction is to be expected. Stainless steel can be successfully soldered and heat treated within the limits we have implied. The industry has developed special instruments and equipment that aid in its application, and further improvements are in the offing.

The materials, instruments and procedures have been critically described in this article according to performance at the clinical level. The techniques referred to have had adequate testing and are in routine use in private practice and clinics. Short-cut procedures or lower standards of performance are not in keeping with the central theme of this symposium or with modern dentistry.

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Analysis of Stress in Dental Structures

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In addition to the biologic considerations which are essential to the success of a dental restorative procedure, it is equally important that no deleterious changes in the size and shape of the restoration occur. Marginal openings between tooth and restoration, the permanent deformation of a dental bridge and the fracture of a restoration are a few examples of changes which cannot be tolerated. These changes can occur in any structure which is acted upon by forces, and dental structures are not exempt in this regard. Forces in the mouth result from mastication, bruxism, occupational and dietary habits, differential thermal expansion between tooth and restoration, placement of the restoration and dimensional changes involved in the setting of certain restorative materials. The manifestation of these applied forces is stress within the restoration as well as in the remaining tooth structure, and these stresses may be accompanied by adverse changes in configuration.

Structural failure occurs when internal stress within the structure due to the application of applied forces reaches a magnitude and extent which can no longer be resisted by the inherent strength of the material from which the structure has been made. Therefore, to establish criteria for continued structural integrity one must determine the nature and magnitude of the internal stress and also the strength properties of the material, and equate this information to see if the structure is being stressed beyond its ability to resist. In engineering practice, each structure is designed so that the relationship of stress to material strength is optimum.

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Since it is obviously impractical for the dental practitioner to analyze each restoration that he places in the manner just prescribed, presently accepted procedure has been to design the configuration of the restoration on the basis of previously determined designs. Since most present designs are based on observed clinical success, the major area of difficulty appears to be in the alteration or, in some instances, in the abuse of these established designs by the general practitioner. In recent studies directed to investigate the incidence and causes of failure of amalgam restorations, 25 to 35 per cent of the failures were attributed to improper cavity designs which reduced the ability of the restorative structures to resist the effects of occlusal forces. Because of these difficulties and in lieu of specific design procedures which may need further evaluation, it was thought desirable to present the fundamental factors involved in the phenomenon of structural failure which can serve as a general guide to the practicing dentist so as to enable him to evaluate his own procedures. In this way, an adverse relationship between internal stress and material strength may be avoided.

In order to facilitate discussion of technical aspects and procedures, each field, including that of stress analysis, has its own vocabulary. Knowing and understanding the vocabulary is essential.

INTERNAL STRESS

Stress may be defined as the internal force per unit of area which resists a change in size or shape of the body. There are several types of stress:

Tensile stress is oriented in a perpendicular direction away from the plane of the cross-sectional area.

Compressive stress is oriented in a perpendicular direction toward the plane of the cross-sectional area.

Shear stress lies within the plane of the cross-sectional area and resists the action tending to make one part of the body slide over another part.

Stress is accompanied by *strain*, which may be defined as the internal deformation per unit of length. In Figure 1 are shown examples of structures loaded to produce compressive stress, tensile stress, and shear stress, respectively, and a beam in bending in which all three stresses are present at the same time. It is significant that a structure subjected to a compressive load may exhibit all three types of stress.

For a given force application, the nature and magnitude of the internal stress is related to the shape or configuration of the structure. Altering the design can change the magnitude of a stress or can change a stress from one type to another. Of particular importance is the con-

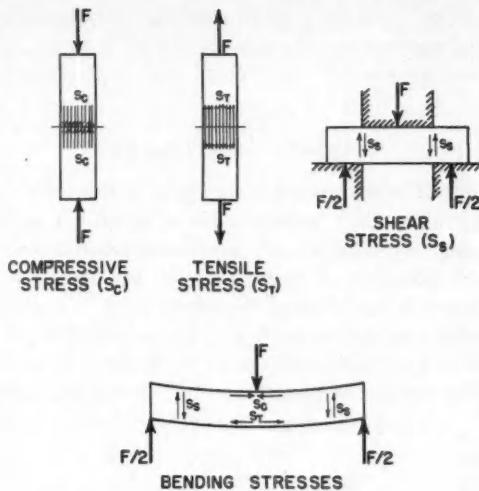


Fig. 1. Types of stresses found in structures subjected to the influence of external forces.

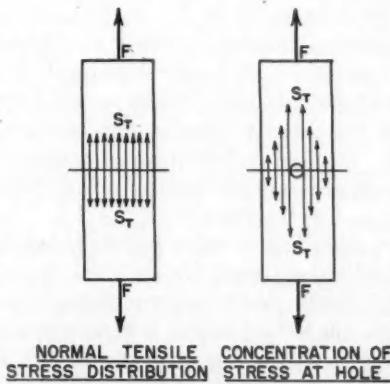


Fig. 2. Example of concentration of stress resulting from a structural discontinuity.

cept of stress concentration. Any discontinuity such as a hole or notch can disrupt an otherwise uniform stress picture and produce a very high stress within the vicinity of the discontinuity. This effect is shown in Figure 2, where a small hole drilled in a bar subjected to tension increased the stress to over twice its normal value at the edge of the hole. The lengths of the stress vectors are drawn to indicate the magnitudes of the stress. In dental application, these discontinuities can be in the form of porosity in a dental casting, a poorly condensed section

of amalgam or gold foil, or a pit in a solder joint. Avoiding these discrepancies in the restorative material by proper manipulative practices is of major consequence in increasing resistance to failure.

STRENGTH OF MATERIALS

For purposes of stress analysis, strength of materials usually is expressed in terms of either the *elastic limit*, which is the stress beyond which permanent deformation of the structure can result, or the *ultimate strength*, which is the stress producing fracture. These two strength parameters are affected by factors such as the type of stress incurred (tensile, compressive, shear, or a combination of these), the time rate of force or load application or whether the loading is alternating and produces the phenomenon of fatigue in the material.

Type of Stress

A specific material often exhibits different values for its ultimate strength in tension, compression, shear or a combination of these stresses such as in bending. It would be necessary to determine the strength of the material subjected to each of these stress conditions, since the proverbial chain will break at its weakest link. Bending is related to the term "edge strength," which is used frequently in dental practice. An edge subjected to bending exhibits tensile, compressive and shear stresses. Fracture in bending is propagated from regions of maximum tensile stress, and when this stress is determined it is referred to as the *modulus of rupture*.

Materials can be classified as either ductile or brittle. Ductile materials can resist tensile stress well, but are weakest under shear stress. On the other hand, brittle materials are extremely weak under tensile stress. Through suitable design practices, shear stress for ductile materials and tensile stress for brittle materials should be minimized or avoided. In addition, whereas the elastic limit is used for the analysis of ductile materials, the ultimate strength is used in the case of brittle materials, since in the latter instance little permanent deformation occurs before fracture.

Rate of Loading

Materials exhibit higher strengths at higher loading rates but are more susceptible to failure if these rates approach impact in nature. Under impact conditions, brittle materials fail very easily and the effect of porosity or discontinuities radically reduces resistance to

failure. The fracture of materials under impact loading is expressed as the *impact strength*, which is the foot-pounds of energy absorbed by the material in fracturing.

Fatigue

This condition refers to failure of a structure under repeated or alternating stress. Alternate applications of loading and unloading produce failure far below the point at which the material would resist a static load of equal magnitude. Fatigue failures are promoted by very small surface defects such as minute cracks or pits. Microscopic pitting due to corrosion can reduce dramatically the strength of a structure. The strength in fatigue is expressed as the *endurance limit*, which is the stress at and below which failure will not occur in a material subjected to an alternating loading system.

STRENGTH OF DENTAL MATERIALS

Dental restorations are subjected to unfavorable conditions of stress. The force application or loading is often impact in nature when a seed or hard foreign object is interposed inadvertently between the teeth during mastication. Alternate force application which produces fatigue is characteristic of the masticatory process. Most dental restorative materials are brittle in nature and are very susceptible to failure under tensile stress. It would therefore be indicated to evaluate the restorative materials on the basis of their tensile strength under these conditions of impact and fatigue. Unfortunately, these determinations have not yet been made and most available information relates to compressive strength with some information on tensile strength and modulus of rupture under static loading conditions.

Values of these properties for dental restorative materials are given in Table 1. Some of these values have been taken from unpublished data while others have come from the dental and engineering literature. Since values for strength can vary over wide ranges depending on material composition, usage and manipulation, the figures reported in this table should be considered as representative rather than specific, and as implying an order of magnitude. It is significant that the compressive strength of these materials offers little evidence of their structural effectiveness, whereas the tensile strength and modulus of rupture are indicative. The superiority of gold is demonstrated by its high tensile strength and high modulus of rupture, whereas the weakness of cements is distinctly corroborated by their low values for these same properties.

TABLE 1. *Mechanical Properties of Dental Restorative Materials*

MATERIAL	COMPRESSIVE STRENGTH (PSI)	TENSILE STRENGTH (PSI)	MODULUS OF RUPTURE (PSI)
Amalgam	45,000	8,000	10,000
Gold alloy (type A)	40,000	40,000	30,000
Silicate cement	23,000	—	1,400
Zinc phosphate cement (cementing consistency)	13,000	—	900
Zinc phosphate cement (base consistency)	14,000	—	1,400
Porcelain	25,000	5,000	8,000
Acrylic resin	14,000	8,000	10,000
Dentin	40,000	40,000	—

STRENGTH OF TOOTH STRUCTURE

It must be recognized that tooth structure also is subjected to forces and stresses. The design of the cavity preparation in a tooth to be restored limits the structural effectiveness of both the restoration to be placed and the remaining tooth structure. Bulk for the restoration can be provided only at the expense of tooth structure, and conversely, conservation of tooth structure can be accomplished only at the expense of the restoration.

Enamel is brittle and may be fractured easily if unsupported. Cleavage is effected most easily in the direction of the enamel rod axes. Dentin, on the other hand, has the necessary toughness for structural support and can resist the dynamic forces of mastication. Although the tensile strength of dentin has not been determined, presumably it is of the order of its compressive strength. This is, of course, when the pulp is vital. Pulpless teeth become brittle as a result of dehydration of the organic portion of the dentin, and restorative design must compensate for this structural deficiency.

PRINCIPLES FOR INCREASING RESISTANCE TO FAILURE

In view of the fundamental concepts which have been stated, it can be concluded that there are several principles which, if followed, can increase the resistance of a restorative material to structural failure. These are:

1. *Alter the design to redistribute or eliminate tensile stress.*
2. *Increase bulk in the region of tensile stress.*
3. *Remove sources of stress concentration in design.*

4. Remove sources of stress concentration due to
 - a. internal porosity and voids;
 - b. surface scratches, grooves or pits.

It should be recognized that stress concentrations may not catalyze failure unless these concentrations occur in regions of maximum stress. Sharp angles or corners in cavity preparation, although producing points of stress concentration, are not deleterious except when high stresses are present and especially when the stresses are tensile in nature.

The main concern in considering the resistance of tooth structure to failure would be to avoid unsupported enamel and to maintain as much supporting dentin as possible.

ANALYSIS OF SOME DENTAL RESTORATIVE DESIGNS

In order to demonstrate how these fundamental concepts can be put into practice, several examples of the evaluation of dental restorative design will be given.

The Two- and Three-surface Amalgam Restoration

In Figure 3 is shown a proximo-occlusal amalgam restoration in a bicuspid. The opposing cusp is exerting forces through a bolus of food acts as a wedge between the marginal ridge and the transverse

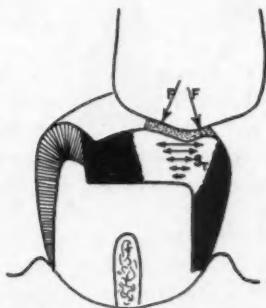


Fig. 3. Tensile stress at the isthmus of a two-surface amalgam restoration.

ridge of the restored tooth. Tensile stresses occur at the isthmus, as shown, and are maximum at the occlusal surface (most maximum stresses occur at a boundary rather than within a structure). Effective interproximal contact, proximal retention, a shallow slope on the marginal ridge and increased cross-sectional area at the isthmus all serve to reduce the tensile stress present. An increase in depth rather

than width at the isthmus is more effective in reducing stress, since increased width increases the total loading area and, therefore, causes no significant reduction in stress. In addition, the supporting tooth structure is weakened by increasing the width of the restoration. Since the maximum stress occurs at the occlusal surface, deeply carved grooves, scratches or pits should be avoided in this area of an amalgam restoration.

The Bevel

In Figure 4, the much-discussed bevel is illustrated. A magnified view of the critical region of this restoration is shown where occlusal forces place the bevel in bending with maximum tensile stresses at the

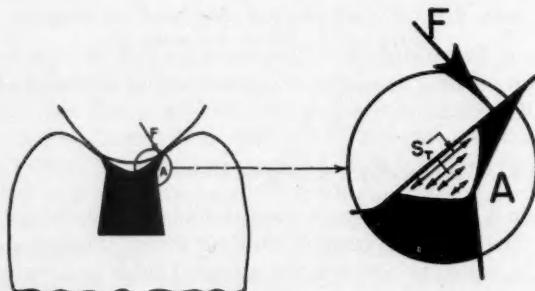


Fig. 4. Tensile stress at the occlusal surface of a beveled amalgam restoration.

occlusal surface. The bending occurs as a result of elastic deformation of the tooth structure beneath the bevel under conditions of occlusal loading. This design is contraindicated for brittle materials such as amalgam, or for other materials with low tensile strengths. Marginal excesses fall within the same category, and fracture usually leaves a ditch around the filling.

The Bridge

The dental bridge consisting of two abutments with a soldered pontic is another example of a beam in bending, which is a well known and evaluated engineering structure. In Figure 5, under the occlusal loading as shown, maximum tensile stresses occur in the gingival regions of the solder joints. The tensile stress can be reduced most radically by increasing the depth dimension of the solder joints. The reduction in stress is proportional to the square of the depth but to only the single power of the width. Increasing the width of the pontic

and solder joints would increase the area of load application so that little strength benefit would be derived from an increase in this dimension.

Another factor in dental bridge design is the amount of bending or deflection of the bridge. Increasing the depth dimension reduces the deflection of the bridge to the cube root of its former value, whereas

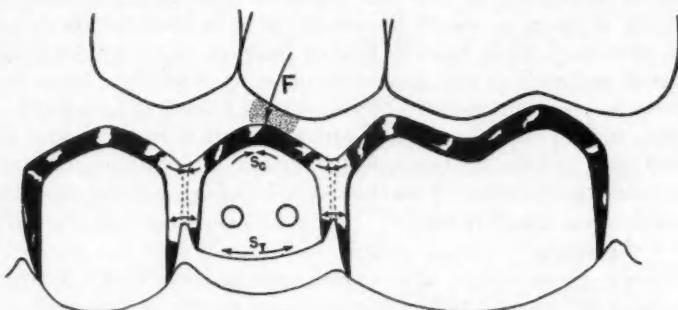


Fig. 5. Tensile stress in the gingival regions of a soldered gold bridge subjected to bending.

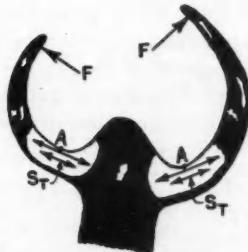


Fig. 6. Tensile stress at the junctions of a partial denture clasp.

changing the width dimension acts only in a linear manner. For example, if the depth dimension is doubled, the deflection is reduced to $\frac{1}{8}$ of its former value, whereas if the width dimension is doubled, the deflection is reduced to only $\frac{1}{2}$ of its former value.

Porosity in castings, or pits or inclusions in the solder joint can reduce resistance to failure, especially if they occur in the gingival regions of the bridge where maximum tensile stresses occur.

The Partial Denture Clasp

In Figure 6 is shown a partial denture clasp which is subjected to stress when the appliance is seated, removed or subjected to unusual

masticatory loads (it has been demonstrated that placement or removal stress is more severe than that imposed by masticatory forces). Once again, the example of a beam in bending exists; in this instance, a cantilever beam is illustrated when the tip of the clasp is deflected over the height of contour of the tooth. Tensile stresses are maximum at points *A* and can be reduced by increasing the bulk of the clasp arms at their junctions with the connector. The junction borders, especially at points *A*, should be curved gently to eliminate the formation of a sharp angle. From its take-off point, the clasp arm should be tapered uniformly in two dimensions down to its retentive tip so that the tip is approximately one-half the width and depth of its point of attachment. This design, combined with the length of the clasp arm, the metal used, and the thickness of the attachment to the connector, will determine the flexibility of the clasp arm. A properly tapered clasp arm reduces stress concentration in a given area and decreases the possibility of breakage.

Besides proper design, other factors must be considered to increase resistance to failure. Among these are sound casting procedures to reduce porosity or inclusions, meticulous waxing to avoid weak or thin areas, inspection of critical areas on the refractory cast for positive discrepancies which will leave voids in the casting, and careful finishing. The grinding and polishing of a partial denture casting should be done parallel to the long axis of the portion being finished. Finishing done perpendicular to the plane of bending may leave grooves, scratches, or weak sections where concentrations in stress will occur, increasing the possibility of fracture.

SUMMARY

In this article, the structural failure of dental restorations has been described, the fundamental basis for these failures has been discussed, and some general principles for increasing the resistance to failure have been enumerated. It is hoped that these concepts will aid the general practitioner in his task of designing the configuration of dental restorations to avoid structural failure.

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Index of Authors

1958

Adams, J. W., 773
Anderson, A. G., 515

Bender, I. B., 119
Bernier, J. L., 325
Berry, D. D., 57
Boyd, D. A., 603
Bruckner, R. J., 91
Burket, L. W., 185, 277
Burkman, N. W., 165

Cheraskin, E., 283
Collins, D. A., 25
Costich, E. R., 195
Coy, H. D., 625
Crowley, M. C., 77
Cunningham, D. M., 653

Dinon, L. R., 335
Docking, A. R., 727
Doty, J. R., 245
Dreizen, S., 429
Dykema, R. W., 653

Epstein, S., 37
Ewing, W. T., 57

Hall, S. G., 625
Harris, S. C., 3
Hartley, J. L., 737
Hayward, J. R., 195
Hill, T. J., 179
Hinds, E. C., 211
Hudson, D. C., 737

Ingersoll, W. B., 137
Johnston, J. F., 653

Keesling, G. R., 211
Kiryat, A. A., 217
Knighton, H. T., 101
Kraus, F. W., 309
Kreshover, S. J., 231
Krogman, W. M., 497

Lovestedt, S. A., 413

Mahler, D. B., 789
Markley, M. R., 815
McClure, F. J., 441
McCracken, W. L., 671
McGavic, J. S., 527
Morgan, C. F., 137
Mosteller, J. H., 585

Noyes, H. J., 489
Ostrander, F. D., 1, 261, 297

Paffenbarger, G. C., 561
Pearlman, S., 251
Peyton, F. A., 759
Phillips, R. W., 545, 457
Pressman, R. S., 351

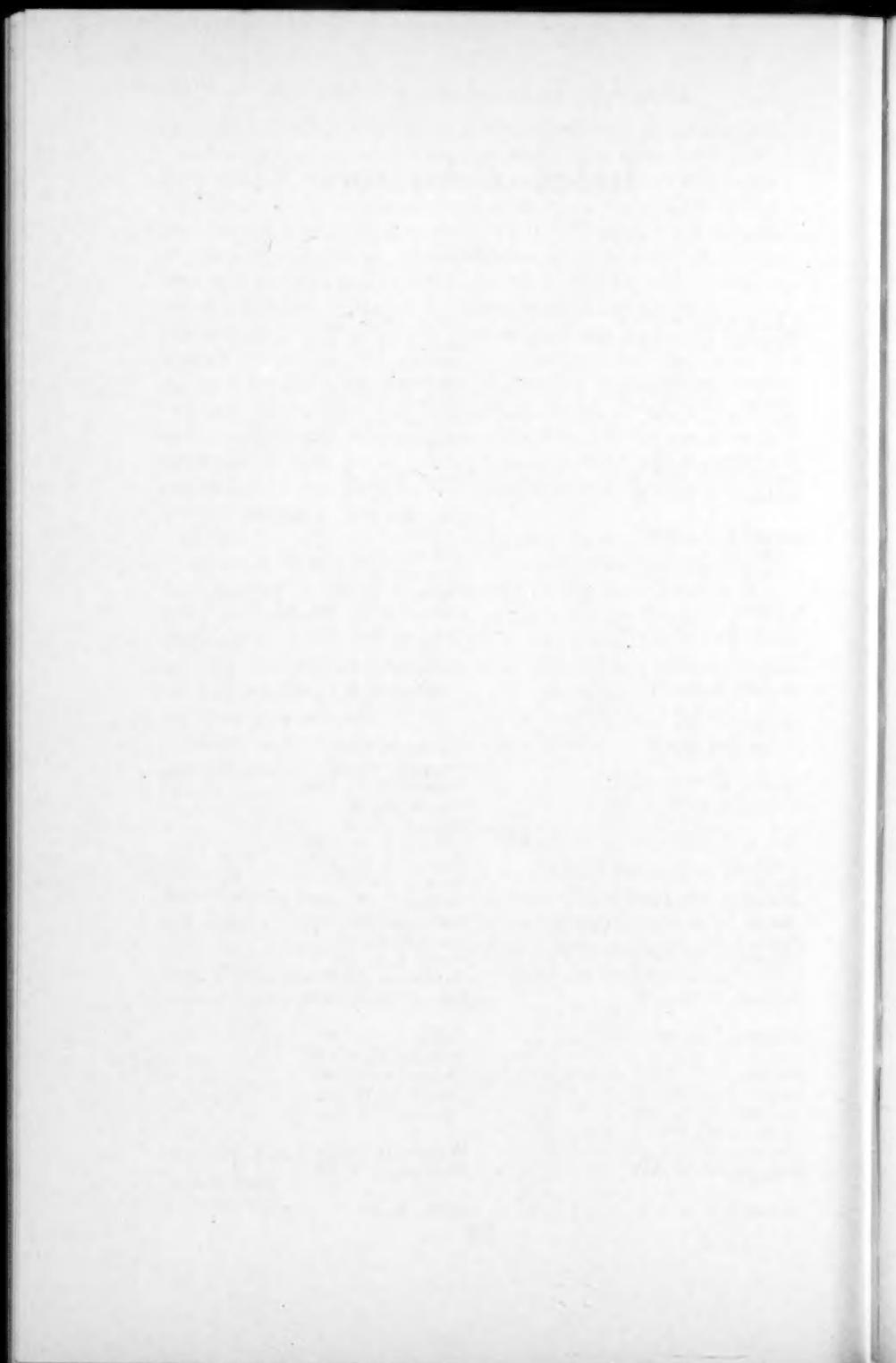
Resch, C. A., 397
Robinson, H. B. G., 471
Ryge, G., 747

Sadove, M. S., 515
Sausen, R. E., 637
Schmidt, H. S., 165
Serr, H. H., 637
Silcox, L. E., 381
Sindoni, A., Jr., 459
Skinner, E. W., 685
Spies, T. D., 429
Stanford, J. W., 561
Stebner, C. M., 571
Stone, R. E., 429
Strang, J. E., 335
Sturdevant, C. M., 699
Sweeney, W. T., 593

Terkla, L. G., 789
Teuscher, G. W., 481
Thomas, A. E., 147
Thomas, C. C., 371
Tylman, S. D., 713

Wallace, D. A., 65
Weisberger, D., 109

Zipkin, I., 441



Index

1957-1958

Page numbers of symposium and clinic titles are given in **boldface** type.

ABRASIVES in dentifrices, 1958: March, 180
Abscesses, alveolar, 1957: July, 521-523
drainage, 1957: July, 524-525
management, 1957: July, 525-526
periapical, 1957: March, 171-172; July, 521
pericemental, 1957: July, 522
pericoronal, 1957: July, 485, 522.
See also *Pericoronitis*.
routes of extension, 1957: July, 523-525
subperiosteal, 1957: July, 523
Accidents in dental office, legal aspects, 1957: July, 597
in endodontics, 1957: Nov., 903-912
instrument. See *Instrument accidents*.
Acetanilid, 1958: March, 67
Acetidine, 1958, March, 267, 268
Acetophenetidin, 1958: March, 21, 67, 267
Acetylsalicylic acid. See *Aspirin*.
Achondroplasia, 1958: July, 416, 483
Achromycin. See *Tetracycline*.
Acinic cell carcinoma, 1957: Nov., 629, 634
Acromegaly, 1958: July, 404, 491
Acrylic resins. See also *Resins, self-curing*.
in prosthetic dentistry, 1958: Nov., 593-602
sensitivity in dentists, 1958: July, 474
Acrylic veneers, 1958: Nov., 654-663
ACTH, 1958: March, 218; July, 297
Actinomyces bovis, 1958: March, 84
Adamantinoma, 1957: Nov., 709-714
Adanon. See *Methadone*.
Addiction, 1958: March, 73, 256
Addison's disease, 1958: July, 484
Adenoameloblastoma, 1957: Nov., 711, 712
Adenocarcinoma, 1957: Nov., 635, 642, 656, 674, 741; 1958: July, 333
Adenocystic carcinoma, 1957: Nov., 633, 658; 1958: July, 333
Adenoma, 1957: Nov., 628, 642, 674
pleomorphic. See *Mixed tumor*.
Adrenal glands, disorders, 1958: July, 406-407
Adrenochrome salicylate in hemostasis, 1958: March, 209
Adrenocortical steroid medication, 1958: March, 217-229; July, 297
Adrenogenital syndrome, 1958: July, 407, 417
Agar impressions, 1957: March, 139-149; 1958: Nov., 680, 717-722
Age factor in denture appearance, 1957: 251, 261-267
Agranulocytosis, 1957: July, 517; 1958: July, 303, 308
Airbrasive technique, 1957: March, 43-53
Airdent. See *Airbrasive technique*.
Airway obstruction, 1957: July, 344-345, 391-397, 451, 584-585, 607, 608
Alazopeptin, 1958: March, 257
Albers-Schönberg disease, 1958: July, 423

Albuminuria, tests, 1958: July, 464

Aldosteronism, primary, 1958: July, 407

Alginate impressions, 1957: March, 149-155, 221; 195: 1958: Nov., 680, 722-724

Allergic reactions, treatment, 1958: March, 144. See also *Hypersensitivity*.

Allergic rhinitis, 1958: March, 234

Allergy. See also *Hypersensitivity*. contact, 1958: March, 236-239 nature of, 1957: July, 441

Alveolalgia. See *Osteitis, alveolar*.

Alveolar abscesses. See *Abscesses*.

Alveolar factors in prosthodontics, 1957: March, 194-199, 207

Alveolar process, fractures, 1957: July, 562

Amalgam restorations, 1957: March, 66-68, 81-106; Nov., 887; 1958: 547-559 cavity liners under, 1958: Nov., 587-590 sensitivity to, 1958: July, 475

Ameloblastoma, 1957: Nov., 680, 709, 739

American Dental Association Council on Dental Therapeutics, 1958: March, 246

Amidone. See *Methadone*.

Aminophylline, 1958: July, 306

Amphetamine, 1958: July, 307

Amphotericin, 1958: March, 257, 258

Amputation neuroma, 1957: Nov., 699

Amyl nitrite, 1958: July, 303

Anachoresis, 1958: July, 316, 318

Analeptics, 1958: July, 522

Analgesics, 1958: 65-176, 144, 254-256, 267-268; July, 304

Anaphylactoid reactions. See *Hypersensitivity*.

Anemia, 1957: July, 359 pernicious, tongue in, 1958: July, 438

Anesthesia as factor in bacteremia, 1958: March, 124; July, 354 general, 1958: March, 57-63 emergencies, 1957: July, 343-348, 607 in heart disease, 1957: July, 410-414; 1958: 347 in diabetes, 1958: July, 468 in pregnancy, 1957: July, 425-428 local, characteristics and use, 1958: March, 37-56, 256

Anesthesia, local, emergencies, 1957: July, 335-343, 435, 607; 1958: March, 54-55 hypersensitivity to, 1958: March, 53, 237 in dentists, 1958: July, 474 injection technique, 1957: July, 497-498 premedication, 1958: July, 520 vasoconstrictors in, 1958: March, 42, 44-45 topical, 1958: March, 48

Anesthetic emergencies, 1957: July, 335-348, 606-608; 1958: March, 54-55 legal aspects, 1957: July, 600

Angiomatous lesions. See *Hemangioma* and *Lymphangioma*.

Angioneurotic edema, 1957: July, 438; 1958: March, 234

Angiosarcoma, 1957: Nov., 643

Angular cheilosis, 1957: March, 291-294; 1958: July, 430

Aniline derivatives as analgesics, 1958: March, 67

Ankylosed teeth as cause of open bite, 1957: March, 274

Anoxia, fetal, 1957: July, 425-427

Antiallergic medication, 1958: July, 306. See also *Antihistamines*.

Antibiotic therapy, dental implications, 1958: July, 299

Antibiotics, effects on oral flora, 1958: March, 77 in cavity medication, 1958: March, 174-176 in dentifrices, 1958: March, 181 in prophylaxis of bacteremias, 1958: March, 129-134; July, 323, 337-339, 361-365, 366-369 in root canal medication, 1957: Nov., 828-831 sensitivity to, 1958: March, 111, 238 systemic, 1958: March, 109-118, 140, 257, 268-269 topical, 1958: March, 101-108, 158-160, 257

Anticoagulant therapy, 1957: July, 360; 1958: July, 298, 339-341

Anticonvulsants, 1958: July, 302

Anti-enzymes in dentifrices, 1958: March, 182

Antigen-antibody reactions, 1957: July, 441

Antihemophilic globulin in hemostasis, 1958: March, 207

Antihistamines, 1958: March, 211-215;
July, 306
in hemostasis, 1958: March, 209
in hypersensitivity reactions, 1957:
July, 342, 343, 437, 446; 1958:
March, 141, 241
in preanesthetic medication, 1958:
March, 62

Antihypertensives, 1958: July, 302, 341

Antileukemic drugs, 1958: July, 308

Antiparasymphathomimetics, 1958:
March, 62

Antisialogogues, 1958: July, 307

Antral lavage, 1957: July, 527

Antral-oral fistula, Berger's sliding flap
technique, 1958: July, 389, 390

APC, 1958: March, 21, 67

Aphthae, recurrent, 1958: March, 85,
139, 225

Aphthous stomatitis, 1957: July, 515-
516; 1958: July, 372, 374

Apical curettage, 1957: Nov., 883

Apical periodontal involvements, 1957:
March, 171-172, 175

Apnea, 1957: July, 345

Appearance phase of denture construc-
tion, 1957: March, 255-268

Apprehension, 1958: March, 5-21

Apresoline, 1958: July, 341

Arrhythmias, cardiac, 1957: July, 346

Arteriosclerosis, hypotensive episodes,
1958: July, 516

Artificial respiration, 1958: July, 523

Ascorbic acid deficiency (case report),
1958: July, 294-296
in hemostasis, 1958: March, 208

Aspirating before injection, 1958:
March, 51.

Aspirin, 1958: March, 21, 65-67, 255,
267

Asthma, 1958: March, 234

Astringents in hemostasis, 1957: July,
363; 1958: March, 205

Ataraxics, 1958: March, 15-20, 144,
253; July, 300-302

Atropine, 1958: March, 21, 267; July,
307

Aureomycin. See *Chlortetracycline*.

Austenitic steels, 1958: Nov., 775

Azaserine, 1958: March, 257

Azochloramid in endodontics, 1958:
March, 154

BACITRACIN in gingival and perio-
dental lesions, 1958: March, 103
in prevention of subacute bacterial
endocarditis, 1958: March, 134

Bacteremias, 1958: March, 121-126;
July, 317-320, 354-362

prophylaxis, 1958: July, 323, 337-
339, 351-370, 362-365, 366-369

Bacteria in caries, 1958: March, 165
in subacute bacterial endocarditis,
1958: March, 120

Bacterial endocarditis, subacute. See
Endocarditis.

Bacterial infections. See *Infections*.

Bacteriologic culture in bacteremia,
1958: July, 355-357

Bacteriology in endodontics, 1957:
March, 178-180; Nov., 845-854;
1958: March, 160-163. See also
Surgical cleanliness.

of oral cavity, 1958: March, 77-89;
July, 309-324

Balanced occlusion, 1957: March, 322,
324

Banthine therapy, 1958: July, 307

Barbiturates in apprehension, 1958:
March, 8-15; July, 300

ultra-short acting, in general anes-
thesia, 1958: March, 59, 62, 63

Basaloid mixed tumor, 1957: Nov.,
633, 658

Base tray. See *Trial denture base*.

Beechwood creosote in endodontics,
1958: March, 154

Behcet's syndrome, 1957: July, 513

Belladonna alkaloids, 1958: March, 21;
July, 307

Benadryl, 1958: July, 306

Benzedrine, 1958: July, 307

Benzoyl peroxide activation of resins,
1957: March, 108

Berger's sliding flap technique in
antral-oral fistula, 1958: July, 389,
390

Binding agents in dentifrices, 1958:
March, 181

Biomechanical preparation in endo-
dontics, 1958: March, 148-151

Biopsy of neck tissue, 1957: Nov., 742

Black hairy tongue, 1958: July, 392

Blastomatoid lesions, odontogenic,
1957: Nov., 714-718

Bleaching discolored teeth, 1957: Nov.,
897-902

Bleeding. See *Hemorrhage* and *He-
mostasis*.

Bleeding rate in oral surgery, 1957:
July, 353

Bleeding time, 1957: July, 350

Blood count, normal values, 1957:
July, 350

Blood dyscrasias, 1957: July, 531; 1958: July, 391

Blood elements in hemostasis, 1958: March, 206

Blood loss in oral surgery, 1957: July, 352

Bone. See also *Jawbones*.
fibrous dysplasia, 1957: Nov., 677, 694, 695
grafts, 1957: July, 455
injuries from instruments, 1957: July, 498
plates in mandibular fractures, 1957: July, 455
wax, 1958: March, 201

Bridge. See *Dentures, fixed partial*.

Bronchospasm, 1957: July, 345
from Pentothal sodium, 1957: July, 448

Buccal mucosa in nutritional deficiency, 1958: July, 437
tumors, 1957: Nov., 661-668

Bulk pack technique for resin restorations, 1957: March, 113-116

Burns, 1957: July, 589
chemical, 1957: July, 499, 504-505

Burs, cutting efficiency, 1957: March, 4, 22-24, 33; 1958: Nov., 737-745

Butethamine, 1958: March, 44, 46

CALCIUM hydroxide in cavity medication, 1958: March, 173; Nov., 586, 588, 611

Caldwell-Luc operation, 1957: July, 387-388, 527

Calf bone, homogenized, 1958: March, 204

Camphorated para-monochlorophenol in endodontics, 1957: Nov., 827; 1958: March, 155

Cancer. See also *Adenocarcinoma*, *Carcinoma*, *Fibrosarcoma*, *Sarcoma*, *Tumors*.
etiology, 1957: Nov., 621-623
facial pain from, 1957: July, 476-479
of oral cavity, clinical features, 1958: July, 325-333
treatment, 1957: Nov., 733-742

Candida albicans, 1958: March, 83. See also *Moniliasis*.

Capillary permeability and fragility, 1957: July, 360-361

Carborundum instruments, cutting efficiency, 1957: March, 33

Carcinoma, 1958: July, 378, 392-394
acinar cell, of salivary glands, 1957: Nov., 629, 634

Carcinoma, adenocystic, 1957: Nov., 633, 658; 1958: July, 333
in situ, 1957: Nov., 640

metastatic, 1957: Nov., 729-731, 741

mucoepidermoid, 1957: Nov., 629, 632, 642, 741; 1958: July, 333

squamous, 1957: Nov., 626, 639, 640, 655, 657, 666, 670, 690, 691; 1958: July, 325-329

transitional, 1957: Nov., 672; 1958: July, 329

treatment, 1957: Nov., 733-742

Cardiac arrest, 1957: July, 346; 1958: July, 524-525

Cardiac arrhythmias, 1957: July, 346

Cardiac disease. See *Heart disease*.

Cardiac insufficiency as orthodontic problem, 1958: July, 492

Cardiac patient as risk in oral surgery, 1957: July, 405-415. See also under *Heart disease*.

Cardiac reserve in oral surgery patient, 1957: July, 407

Cardiac status, 1958: July, 343

Cardiovascular emergencies in general anesthesia, 1957: July, 346

Caries, activity tests, 1958: March, 81
as endogenous infection, 1958: July, 315
bacteria in, 1958: March, 79, 80-82, 165
in pregnancy, 1957: July, 418
nutritional aspects, 1958: July, 438-440
prevention, 1958: March, 81

Case-finding opportunities of dentist, 1958: July, 283-296

Casting procedures, 1957: March, 71-73; 1958: Nov., 625-636, 637-651
chromium-cobalt alloys, 1958: Nov., 767-770

Cataract, 1958: July, 528

Causalgia, 1958: March, 34

Caustics in hemostasis, 1958: March, 205

Cauterization as factor in bacteremia, 1958: July, 359
in hemostasis, 1958: March, 205

Cavitron. See *Ultrasonic technique*.

Cavity liners and intermediate base materials, 1957: March, 87; 1958: Nov., 585-592

Cavity medication, 1958: March, 165-177

Cavity preparations, airabrasive technique, 1957: March, 45-47, 49-53

Cavity preparations, class I, 1957:
 March, 6, 129
class II, 1957: March, 7-12, 82-
 87, 130-132
class III, 1957: March, 12-14,
 132-135
class IV, 1957: March, 14-15;
 1958: Nov., 575, 583
class V, 1957: March, 16, 135-137
for resin restorations, 1957:
 March, 111-113
general principles, 1957: March,
 3-17
high speed, 1957: March, 27,
 31-42
ultrasonic technique, 1957: March,
 59-62

Cavity sterilization, 1957: March, 87

Cementoma, 1957: Nov., 717-718

Cements, zinc phosphate and silicate,
 1958: Nov., 561-569. See also *Silicate cements*.

Centric occlusion, 1957: March, 315,
 317-319

Centric relation, 1957: March, 237-
 239, 314, 317-319

Cephalometry, 1958: July, 507, 508

Cerebral hypoxia, 1957: July, 347

Cheilosis, 1958: March, 225; July, 430

Chemical burns, 1957: July, 499, 504-
 505

Chest injuries, 1957: July, 585-587

Chewing cycle, 1957: March, 208-209

Children, drug dosages for, 1958:
 March, 262
systemic diseases, 1958: July, 481-
 488

Chloramine-T in endodontics, 1958:
 March, 154

Chloramphenicol, 1958: March, 118
 in prophylaxis of bacteremia, 1958:
 March, 130, 132; July, 364, 369

Chlorine compounds in root canal med-
 ication, 1957: Nov., 827

Chloroazodin in endodontics, 1958:
 March, 154

Chloromycetin. See *Chloramphenicol*.

Chlorpromazine, 1958: March, 16-18,
 253; July, 301

Chlortetracycline, 1958: March, 117
 in cavity medication, 1958: March,
 175
 in gingivitis, 1958: March, 140
 in prophylaxis of bacteremia, 1958:
 March, 130; July, 364, 367

Chondrodystrophy, atypical, 1958:
 July, 482

Chondroma, 1957: Nov., 698

Chondrosarcoma, 1957: Nov., 723-725;
 1958: July, 331

Choristoma, 1957: Nov., 645

Choroiditis, 1958: July, 528

Chromium sensitivity in dentists,
 1958: July, 475

Chromium-cobalt alloys, 1958: Nov.,
 759-771

Circulatory collapse, 1957: July, 434-
 435

Circulatory disease in dentists, 1958:
 July, 478

Circulatory standstill, 1957: July, 346;
 1958: July, 524

Clark's rule, 1957: July, 368; 1958:
 March, 263

Cleft palate, relation to stress in preg-
 nancy, 1957: July, 423-424

Cleidocranial dysostosis, 1958: July,
 416, 482

Clot retraction time, 1957: July, 351

Coagulants, 1957: July, 362-364

Coagulation of blood, 1958: March, 197
 time, 1957: July, 350

Cobefrin in local anesthetics, 1958:
 March, 43

Codeine, 1958: March, 68-71, 268

Collagen diseases, 1958: March, 235

Compazine, 1958: March, 18

Complete dentures. See *Dentures*.

Composite odontoma, 1957: Nov., 715-
 717

Condylar heads, relation to glenoid
 fossa, 1957: March, 317

Condylar movements, immutability of,
 1957: March, 321

Condyle path in complete denture
 technique, 1957: March, 226

Congenital anomalies, relation to
 stress in pregnancy, 1957: July,
 423-424

Congo red in hemostasis, 1958: March,
 208

Connective tissue tumors of lips,
 1957: Nov., 643
 of palate, 1957: Nov., 675

Constitutional inferiority as orthodontic
 problem, 1958: July, 493

Contact allergy, 1958: March, 236-
 239; July, 379

Convulsions, 1957: July, 347, 436

Coolants, 1957: March, 20-22, 29, 87

Copal varnishes, 1958: Nov., 588

Co-Pyronil, 1958: March, 212

Coronary disease, 1957: July, 433-434.
 See also *Heart disease*.

Corticotropin, 1958: March, 218; July,
 297

Cortisone, 1958: March, 218; July, 297

Craniometry, 1958: July, 507, 508

Creosote in cavity medication, 1958: March, 168

in endodontics, 1958: March, 154

Cretinism, 1958: July, 398

Cristobalite inlay casting technique, 1957: March, 71

Crown preparations, high speed, 1957: March, 38

rubber base impression techniques, 1957: March, 165

Crowns for pulpless teeth, 1957: Nov., 894

veneered gold, 1958: Nov., 653-669

Culture techniques as factor in bacteremia, 1958: July, 355-357

Culture testing in endodontics, 1957: March, 178-180; Nov., 850-853; 1958: March, 160-163

Cushing's syndrome, 1958: July, 406

Cutaneous diseases, 1958: March, 185-193; July, 371-380

Cyclopropane anesthesia in heart disease, 1957: July, 414

Cylindroma. See *Carcinoma, adenocystic*.

Cystadenoma lymphomatous, papillary, 1957: Nov., 629-630

Cystectomy, hemorrhage in, 1957: July, 354

Cysts, apical periodontal, 1957: March, 172

dentigerous, 1957: Nov., 703, 704, 713

developmental (fissural), 1957: Nov., 700-702

odontogenic, 1957: July, 528; Nov., 703-705

of minor salivary glands, 1957: Nov., 665

periapical, 1957: Nov., 781

traumatic, 1957: Nov., 706-707

DECAY. See *Caries*.

Demerol. See *Meperidine*.

Dental age, 1958: July, 501-502

Dental granuloma, 1958: March, 97

Dental materials, symposium, 1958: Nov., 547-598

Dental significance of systemic medication, 1958: July, 297-308

Dentifrices, therapeutic, 1958: March, 179-184

Dentigerous cyst, 1957: Nov., 703, 704, 713

Dentists, occupational diseases, 1958: July, 471-480

Dentogenics, 1957: March, 247-249, 261

Denture appearance, 1957: March, 245-254, 255-268

Denture base, materials, 1957: March, 229

trial, 1957: March, 231-243

Denture construction, staggered porcelain and plastic set-up, 1957: March, 267

Denture injury enlargement, 1957: Nov., 663

Denture materials, allergies to, 1957: March, 218; 1958: March, 239; July, 474

Denture stability and retention, physiologic factors, 1957: March, 191-197, 199-200

Dentures, complete, technique, 1957: March, 215-230. See also *Trial Denture Base*.

esthetic factors, 1957: March, 245-254, 255-268

fixed partial, criteria for, 1957: March, 299-311

impression techniques, rubber base, 1957: March, 165

postsurgical, edentulous maxillary arch, 1957: Nov., 743-745

malpositioned abutments, 1957: Nov., 747-748

partially edentulous arch, 1957: Nov., 745-747

Dermatitis, contact, in dentists, 1958: July, 474-476

venenata, 1958: July, 379

Dermatologic diseases, 1958: March, 185-193; July, 371-380

Dermatoses, vesicular, 1957: July, 512-514

Desensitization by vaccines, 1958: March, 241

Desoxycorticosterone, 1958: March, 218

Desoxyephedrine, 1958: July, 307

Development and growth, 1958: July, 497-514

Dexedrine, 1958: July, 307

Diabetes insipidus, 1958: July, 482

Diabetes mellitus, 1957: July, 516; 1958: July, 292, 305, 407, 459-469, 485

Diagnosis and prognosis of edentulous mouth, 1957: March, 187-201

differential, of prosthodontic needs, symposium, 1957: March, 185-325

of pain of dental origin, 1957: July, 463-466; Nov., 775-787

Diagnostic factors in choice of posterior occlusion, 1957: March, 203-213

Diamond instruments, cutting efficiency, 1957: March, 24-25, 33; 1958: Nov., 737-745

Dicumarol, 1958: July, 298, 340

Diet and nutrition in edentulous patient, 1957: March, 285-298
in etiology of open bite, 1957: March, 280
in preparation for dentures, 1957: March, 219

Differential diagnosis of prosthodontic needs, symposium, 1957: March, 185-325

Digitalis, 1958: July, 303

Dilantin sodium hyperplasia, 1957: Nov., 684; 1958: March, 143, 224; July, 302

Diphenylhydantoin. See *Dilantin sodium*.

Direct-filling resins, 1957: March, 78-80, 107-122

Disease, oral and systemic, interrelationship, symposium, 1958: July, 277-531

Disinfecting methods in endodontics, 1957: Nov., 838, 840-843

Displacement of teeth, 1957: July, 373-376

Diuretics, mercurial, 1958: July, 291, 303

Dolantin. See *Meperidine*.

Dolophine. See *Methadone*.

Drug addiction, 1958: March, 73, 256

Drugs. See also under drug names and under types, e.g., *Analgesics*.
allergy to, 1957: July, 435-438; 1958: March, 236-239; July, 474-476
analgesic, in control of dental pain, 1958: March, 65-76
clinical evaluation, 1958: March, 248
dosages for children, 1958: March, 262
for emergency use, 1958: July, 521
in periodontal infections and inflammation, 1958: March, 137-145
prescription writing, 1958: March, 261-269
research trends, 1958: March, 251-259
role of evaluating agencies, 1958: March, 245-250
shock-like reactions from, 1957: July, 443

Dry socket. See *Osteitis, alveolar*.

Duocaine, 1958: March, 45

Dust hazards to dentists, 1958: July, 476

Dwarfism, 1958: July, 416, 483, 484

EAR, nose and throat diseases of interest to dentist, 1958: July, 381-396

Ectodermal dysplasia, 1958: July, 416, 483

Edema, angioneurotic, 1957: July, 438; 1958: March, 234

Edentulous patient, diagnosis and prognosis of rehabilitation, 1957: March, 187-201
diet and nutrition in, 1957: March, 285-298

Electromedication in endodontics, 1958: March, 156-158

Embedded roots, 1957: July, 379-390.
See also *Root Fragments*.

Emergencies, anesthetic, 1957: July, 335-348; 1958: March, 54-55
armamentarium, 1957: July, 605-608; 1958: July, 520-522
in dental practice, symposium, 1957: July, 333-608
resuscitation, 1958: July, 515-526

Emergency treatment, legal aspects, 1957: July, 593-604

Enamel rods, 1957: March, 5

Endocarditis, subacute bacterial, 1958: March, 119-136; July, 304, 318, 319, 335-339

Endocrine disturbances as cause of open bite, 1957: March, 273
oral manifestations, 1958: July, 391, 397-411

Endodontic infections, streptococci in, 1958: March, 78-79
therapeutic management, 1958: March, 147-163

Endodontics, 1957: March, 167-184.
See also under *Pulp*.
accidents, 1957: Nov., 903-912
apical curettage, 1957: Nov., 883
bacteriology, 1957: March, 178-180; Nov., 845-854. See also *Surgical cleanliness*.
bleaching discolored teeth, 1957: Nov., 897-902
cavity preparation, 1957: Nov., 809-822
conditions in which treatment is inadvisable, 1957: Nov., 772
conditions indicating questionable prognosis, 1957: Nov., 766-772

Endodontics, contraindications, 1957: Nov., 762-766
 coronal restoration of treated pulpless tooth, 1957: Nov., 885-896
 hormones in, 1958: March, 225
 instrument storage, 1957: Nov., 807, 843
 instruments and instrumentation, 1957: March, 175-177; Nov., 805-822
 modern practice in, symposium, 1957: Nov., 759-912
 obturation of root canal, 1957: March, 180-183; Nov., 855-871
 root canal medication, 1957: Nov., 823-834
 root resection, 1957: Nov., 873-883
 selection of teeth for treatment, 1957: March, 167; Nov., 761-774
 subacute bacterial endocarditis and, 1958: March, 127
 surgical cleanliness, 1957: Nov., 835-844
 topical antibiotics in, 1958: March, 105-107
 Eosinophilic granuloma, 1957: Nov., 689
 Ephedrine, 1958: March, 144; July, 306
 Epilepsy, 1958: July, 486
 Epinephrine, 1958: March, 43, 144; July, 522
 Epithelial tumors, 1957: Nov., 628, 638, 669
 Epithelioma adenoides cysticum. See *Carcinoma, adenocystic*.
 squamous, 1957: Nov., 666
 Epithelitis, irradiation, 1958: July, 394
 Epulis fissuratum, 1957: Nov., 663
 of chronic hyperplastic gingivitis, 1957: Nov., 685
 Equanil, 1958: March, 19
 Equipment, emergency, 1957: July, 605-608
 Eruption schedules, 1958: July, 508
 Erythema multiforme, 1957: July, 512; 1958: March, 187, 227; July, 372, 374
 Erythromycin, 1958: March, 116, 269; July, 364, 367, 369
 Esthetics in denture construction, 1957: March, 245-254, 255-268
 Ethchlorvynol, 1958: March, 254
 Ethinamate, 1958: March, 254
 Eugenol in cavity medication, 1958: March, 169
 in endodontics, 1958: March, 153
 Ewing's sarcoma, 1957: Nov., 726, 739; 1958: July, 331
 Examination, physical, 1958: July, 518-520
 Exodontia, accidental injuries, 1957: July, 493
 as factor in bacteremia, 1958: July, 318-320, 357
 hemorrhage, 1957: July, 349-365
 Extraction wounds, retarded healing, 1957: July, 533-545. See also *Osteitis, alveolar*.
 topical antibiotics in, 1958: March, 105
 Extrusion of teeth, 1957: July, 373, 376
 Eye diseases in dentists, 1958: July, 476
 relationship of oral infection to, 1958: July, 527-531
 FACE, injuries, 1957: July, 557-571
 Facial defects, prostheses, 1957: Nov., 749-758
 Facial giantism, 1958: July, 417
 Facial pain, diagnosis, 1957: July, 463-480. See also under *Pain*.
 Facio-dental growth, 1958: July, 507
 Fainting. See *Syncope*.
 Familial fibrous dysplasia, 1957: Nov., 695
 Ferritic steels, 1958: Nov., 775
 Fibrin sponge, 1958: March, 204
 Fibroadenoma, congenital, 1957: Nov., 684
 Fibroameloblastoma, 1957: Nov., 714, 715
 Fibroepithelial lesion, 1957: Nov., 662-663
 Fibroma, 1957: Nov., 635, 644, 648, 664, 675, 680, 681, 696
 irritation, 1957: Nov., 639, 643, 662
 odontogenic, 1957: Nov., 714, 715
 ossifying, 1957: Nov., 681
 periapical, 1957: Nov., 781
 Fibromatosis gingivae, 1957: Nov., 682-683
 of tuberosity, 1957: Nov., 683
 Fibro-osseous lesions of jaws, 1957: Nov., 693-696
 Fibrosarcoma, 1957: Nov., 644, 675, 691, 725; 1958: July, 330, 331
 Fibrous dysplasia, 1957: Nov., 677, 694, 695; 1958: July, 422
 Filling materials, selection, 1957: March, 65-80. See also specific materials, e.g., *Amalgam*.
 Filling of root canal, 1957: July, 180-183; Nov., 855-871
 First aid, 1957: July, 579-592
 legal aspects, 1957: July, 601-603

Fistula, antral-oral, Berger's sliding flap technique, 1958: July, 389, 390

Fixed prosthesis. See *Dentures, fixed partial*.

Flange factors in denture appearance, 1957: March, 258

Floor of mouth and tongue, tumors, 1957: Nov., 847-660

Flow technique for resin restorations, 1957: March, 116-117

Fludrocortisone, 1958: March, 219

Fluoride in dentifrices, 1958: March, 183

physiologic effects as related to water fluoridation, 1958: July, 441-458

Fluorohydrocortisone, 1958: March, 219

Fluorosis, 1958: July, 449, 450

Focal infection, 1958: July, 320-323, 529

in pregnancy, 1957: July, 418

Foil. See *Cold foil*.

Folic acid deficiency, 1958: July, 436

Food allergies, 1958: March, 238

Foot problems of dentists, 1958: July, 477

Foramina, relation to alveolar ridge resorption, 1957: March, 197-199

Fordyce's disease, 1958: July, 380

Foreign bodies in maxillary sinus, 1957: July, 527

legal aspects, 1957: July, 402-403, 596

management, 1957: July, 391-404

retention, 1957: July, 494-497

Formocresol in endodontics, 1958: March, 154

Fractured roots, removal, 1957: July, 379-390. See also *Root fragments*.

Fractures, anterior teeth, 1957: July, 367-377; Nov., 892-894

compound, 1957: July, 591

extremities, 1957: July, 591

mandibular, 1957: July, 454-456, 566

maxillary, 1957: July, 456, 557-562

determination of occlusion, 1957: July, 567

maxillofacial, 1957: July, 451-462

open, 1957: July, 591

spinal, 1957: July, 591

zygomatic, 1957: July, 456, 563-565

Froehlich's syndrome, 1958: July, 403

Full dentures. See *Dentures*.

Fungi in oral cavity, 1958: March, 83-85

Fungus infections, 1957: July, 507, 511

Fused porcelain veneers, 1958: Nov., 663-669

Fusospirochetosis, 1958: March, 82

in pericoronitis, 1957: July, 483

tongue lesions, 1957: July, 506

GANGLIONIC blocking agents, 1958: July, 341

Gastro-intestinal emergencies in general anesthesia, 1957: July, 348

Gelatin sponge, 1958: March, 204

General anesthesia. See under *Anesthesia*.

Geographic tongue, 1958: March, 225; July, 380

Giant cell reparative granuloma, 1957: Nov., 687, 695

Gigantism, 1958: July, 417, 482, 483

Gingiva in leukemia, 1957: Nov., 691

in nutritional deficiency, 1958: July, 435-437

in pregnancy, 1957: July, 419-422; Nov., 686

tumors, 1957: Nov., 679-692

Gingival disease, antibiotics in, 1958: March, 102-104, 140

Gingivectomy in pericoronitis, 1957: July, 486

Gingivitis, hormonal, 1958: March, 224

necrotizing, 1957: July, 506

pregnancy, 1957: July, 419-420

Gingivostomatitis, herpetic, 1957: July, 508-509

Glaucoma, 1958: July, 528

Globulomaxillary cyst, 1957: Nov., 702

Glossitis, 1958: July, 432-433. See also *Tongue*.

benign migratory, 1958: July, 380

in nutritional deficiency, 1957: March, 291, 292

Glossopharyngeal neuralgia, 1957: July, 472

Glutethimide, 1958: March, 254

Gold alloys in small castings, 1958: Nov., 637-651

Gold crowns for pulpless teeth, 1957: Nov., 894

veneered, 1958: Nov., 653-669

Gold foil, 1957: March, 73-75, 123-137; 1958: Nov., 571-584

cavity preparations, 1957: March, 7, 9-10, 12-13, 16, 129-137;

1958: Nov., 575, 583

liners under, 1958: Nov., 590

Gold inlays, 1957: March, 68-73; Nov., 888-892
 casing procedures, 1957: March, 71-73; 1958: Nov., 625-636, 637-651
 cavity preparation, 1957: March, 11, 13-15, 18
 impression techniques, hydrocolloid, 1957: March, 139-155
 rubber base, 1957: March, 157-166
 liners under, 1958: Nov., 590
 Gonads, disorders, 1958: July, 406
 Gottlieb's solutions, 1958: Nov., 588
 Grafts, bone, 1957: July, 455
 Granular cell myoblastoma, 1957: Nov., 639, 645, 650, 682
 Granuloma, dental, 1958: March, 97
 eosinophilic, 1957: Nov., 689
 giant cell reparative, 1957: Nov., 687, 695
 periapical, 1957: March, 172; Nov., 780
 pyogenicum, 1957: Nov., 652, 655, 663, 664, 687
 Growth and development problems, 1958: July, 497-514
 Growth factor in etiology of open bite, 1957: March, 270-273
 Gutta percha in root canal obturation, 1957: March, 181; Nov., 859-864

HALOGENS in root canal medication, 1957: Nov., 827
 Hamartoma of lips, 1957: Nov., 645
 Headache, Hórtón's, 1957: July, 473
 Heart. See also *Cardiac* and *Cardiovascular*.
 Heart disease, anesthesia in, 1957: July, 410-414
 coronary, 1957: July, 433-434
 dental patient and, 1958: July, 335-350
 operative mortality rates in, 1957: July, 405
 oral surgery and, 1957: July, 405-415
 premedication in, for prevention of subacute bacterial endocarditis, 1958: March, 119-136
 Heat generation in high speed instruments, 1957: March, 20-22
 Hemangioma, 1957: Nov., 712
 Hemangioblastoma, 1957: Nov., 643, 654, 676
 Hemangioma, 1957: July, 518, 547-556; Nov., 635, 639, 642, 652, 653, 663, 664, 676, 684, 685, 697
 Hemiatrophy, 1958: July, 484
 Hemihypertrophy, 1958: July, 417, 484
 Hemophilia, 1957: July, 358; 1958: July, 486
 Hemorrhage, control, 1957: July, 349-365, 569, 582-584, 605; 1958: March, 195-210; July, 340
 Hemorrhagic cyst of jawbones, 1957: Nov., 706-707
 Hemorrhagic disorders, 1957: July, 357-360
 history, 1957: July, 349
 laboratory tests, 1957: July, 350-351
 Hemorrhagic shock, 1957: July, 438
 Hemostatic agents, 1957: July, 362-364; 1958: March, 142, 199-209
 Hemothorax, 1957: July, 586
 Heparin medication, 1958: July, 298, 339
 Hepatitis, 1958: March, 87
 Heredity in face and teeth, 1958: July, 512
 Herpangina, 1957: July, 509
 Herpes simplex, 1958: March, 139, 189-191; July, 378
 Herpes zoster, 1957: July, 509; 1958: March, 191
 Herpetic gingivostomatitis, 1957: July, 508-509; 1958: March, 85; July, 372
 Herpetic lesions in pregnancy, 1957: July, 422
 Hesperidin, 1958: March, 209
 Heterotopic nodes, 1957: Nov., 668
 Hexobarbital, 1958: March, 266
 High speed instruments, 1957: March, 19-30
 cutting efficiency, 1958: Nov., 737-745
 list, 1957: March, 41
 preparations, 1957: March, 31-42
 patient reaction, 1957: March, 27, 34
 Hinge axis, 1957: March, 320
 Histamine cephalgia, 1957: July, 473
 Histoplasmosis, 1957: July, 511; 1958: March, 88
 History-taking, 1958: July, 518-520
 Horizontal extensions in complete denture technique, 1957: March, 226
 Hormonal hyperplasia of pregnancy, 1957: July, 419-422; Nov., 686
 Hormones, adrenocortical, in oral conditions, 1958: March, 217-229; July, 297

Horton's headache, 1957: July, 473

Hydrocolloid impression materials, 1957: March, 139-155; 1958: Nov., 680, 713-725. See also *Impressions*.

Hydrocortisone, 1958: March, 218; July, 297, 386

Hydroxyzine, 1958: March, 18

Hygrosopic expansion inlay casting technique, 1957: March, 72; 1958: Nov., 625-636

Hyoscyamine, 1958: March, 21

Hyperadrenocorticism, 1958: July, 406

Hyperkeratosis, 1957: Nov., 623, 640

Hyperparathyroidism, 1958: July, 400, 421

Hyperpituitarism, 1958: July, 404

Hyperplasia, gingival, in pregnancy, 1957: July, 419-422; Nov., 686

papillary, 1957: Nov., 624

unilateral, 1958: July, 417

Hypersensitivity, 1957: July, 441-450. See also *Allergy*.
as orthodontic problem, 1958: July, 492
in dentists, 1958: July, 474-476
nature of, 1958: March, 231-233
oral manifestations, 1958: March, 239; July, 306
treatment, 1958: March, 231-243
to denture materials, 1957: March, 218
to drugs, 1958: March, 53, 141, 236-239
to local anesthetic, 1957: July, 341-343, 435. See also under *Procaine*.
to penicillin, 1957: July, 436-438

Hypersensitivity reactions, tongue, 1957: July, 514-515

Hypertension, hemorrhage and, 1957: July, 361

Hyperthyroidism, 1958: July, 399-400, 417, 482

Hypnotics, 1958: March, 143. See also *Sedation*.

Hypoadrenia, 1958: July, 406

Hypoparathyroidism, 1958: July, 401, 419

Hypopituitarism, 1958: July, 402-404, 415

Hypoprothrombinemia, 1957: July, 359

Hypotensive episodes, 1958: July, 516

Hypothyroidism, 1958: July, 397-399, 415, 482, 491

Hypoxia, cerebral, 1957: July, 347; 1958: March, 58

Hysteria, 1957: July, 433

IDIOSYNCRASY. See *Hypersensitivity*.

Ilotycin. See *Erythromycin*.

Impactions, pain from, 1957: July, 464

Impression materials for prosthetic dentistry, 1958: Nov., 671-684

hydrocolloid, 1957: March, 139-155, 221; 1958: Nov., 680, 713-725

rubber base, 1957: March, 157-166; 1958: Nov., 681, 685-697, 699-711

Impression waxes, 1958: Nov., 677-680

Impressions, checking with trial denture base, 1957: March, 234

final, in complete denture technique, 1957: March, 224

preliminary, in complete denture technique, 1957: March, 221

Incisors, fractures, 1957: July, 367-377; Nov., 892-894

permanent, displacement, 1957: July, 373-374

Infection(s) as hazard to dentists, 1958: July, 478

bacterial, 1957: July, 505-507, 510-511

endogenous, 1958: July, 314-316

exogenous, 1958: July, 313

focal, 1958: July, 320-323, 529

in pregnancy, 1957: July, 418

inflammatory reactions in response, 1958: March, 91-99

mycotic, 1957: July, 507, 511

non-surgical systemic effects, 1958: July, 320-322

of dental origin, 1957: July, 521-532. See also *Abscesses*.

of salivary glands, 1957: July, 531

oral, relation to eye, 1958: July, 527-531

pre- and postoperative, in heart disease, 1957: July, 410

sinus, 1957: July, 466-469, 526-528

streptococci in, 1958: March, 78-80

systemic antibiotics in, 1958: March, 110

transmission from oral cavity, 1958: July, 316

Vincent's, 1958: March, 82

viral, 1957: July, 508-510; 1958: March, 85

Inflammations. See also *Abscesses* and *Infections*.

after immediate dentures, hormonal therapy, 1958: March, 221

of salivary glands, 1957: July, 529-531

Inflammatory reactions, influence on therapy, 1958: March, 91-99

Injection technique, 1957: July, 497-498

Injuries, bone, from instruments, 1957: July, 498

 chest, 1957: July, 585-587

 evaluation, 1957: July, 581-582

 first aid, 1957: July, 579-592

 maxillofacial, 1957: July, 557-571

 soft tissue, from instruments, 1957: July, 490-493

Inlays. See *Gold inlays*.

Instrument accidents, prevention, 1957: July, 489-501

Instrument storage in endodontics, 1957: Nov., 807-843

Instrumentation in cavity preparation, 1957: March, 3

Instruments, cutting efficiency, 1957: March, 24-25, 33; 1958: Nov., 737-745

 high speed. See under *High speed*.

Insulin in diabetes, 1958: July, 305

Interrelationship of oral and systemic disease, symposium, 1958: July, 277-531

Intracutaneous tests for hypersensitivity, 1957: July, 443

Intrusion of teeth, 1957: July, 373, 375

Iodine in root canal medication, 1957: Nov., 827

Iridocyclitis, 1958: July, 528

Iritis from oral infection, 1958: July, 318

Irradiation epithelitis, 1958: July, 394

Irrigation in endodontics, 1958: March, 149-151

Irritation fibroma, 1957: Nov., 639, 643, 662

Isonipecaine. See *Meperidine*.

JACKET preparations, high speed, 1957: March, 39-41

Jaw relations, 1957: March, 313-325.

 See also *Occclusion*.

 in denture technique, 1957: March, 220, 224-227

Jawbones, benign tumors and cysts, 1957: Nov., 693-708

 fractures. See *Fractures*.

malignant tumors, 1957: Nov., 721-731, 739; 1958: 331-332

Juvenile hemangiomas, 1957: Nov., 635, 639, 642

KAZANJIAN locator, 1957: July, 400-401

Keloids, 1958: March, 225

Ketosis, urine tests, 1958: July, 463

Kincaine, 1958: March, 45, 47

LABIAL and buccal mucosa, tumors, 1957: Nov., 661-668

Lacerations, immediate care, 1957: July, 568-570

 of tongue, 1957: July, 503-504

Lactobacilli in caries, 1958: March, 80-82

Largactil, 1958: March, 16-18

Laryngospasm, 1957: July, 344-345

 from Pentothal sodium, 1957: July, 448

Legal aspects of emergency treatment, 1957: July, 593-604

 of instrument accidents, 1957: July, 500

Leiomyoma, 1957: Nov., 645, 650

Leiomyosarcoma, 1957: Nov., 645

Leontiasis ossea, 1958: July, 483

Leukemia, 1957: July, 359, 517; Nov., 691; 1958: March, 223; July, 330, 485

Leukoplakia, 1957: Nov., 623, 640, 656, 657, 666, 667; 1958: March, 225; July, 377, 393

Levo-arterenol in local anesthetics, 1958: March, 43

Lichen planus, 1958: March, 186, 225; July, 375, 377

 eruptive, 1957: July, 513, 514

Lidocaine, 1958: March, 45, 47

Lipofibroma, 1957: Nov., 648, 651, 681

Lipoma, 1957: Nov., 635, 644, 667

Lips in nutritional deficiency, 1958: July, 430

 tumors, 1957: Nov., 626, 637-646; 1958: July, 327

Local anesthesia. See *Anesthesia, local*.

Lupus erythematosus, 1957: July, 513; 1958: March, 222, 235; July, 376, 377

Lymphangioma, 1957: Nov., 639, 643, 652, 654, 664

Lymphoepithelioma, 1958: July, 329

Lymphoma, 1957: Nov., 668

MALIGNANT growths of oral cavity, clinical features, 1958: July, 325-333. See also specific types, e.g., *Carcinoma*.

Malignant neutropenia. See *Agranulocytosis*.

Malocclusion, relation to aural symptoms, 1958: July, 381-386

 secondary to nasal disorders, 1958: July, 387

Mandible, fractures. See *Fractures*.

Mandibular movements in choice of posterior occlusion, 1957: March, 206

Mandibular rami in denture retention, 1957: March, 199

Marble bones, 1958: July, 423

Martensitic steels, 1958: Nov., 774

Masticatory cycle, 1957: March, 208-209, 319

Materials, dental, symposium, 1958: Nov., 547-798

Matrix retainers, 1957: March, 90-93

Maxilla, fractures. See *Fractures*.

Maxillary and facial injuries, 1957: July, 557-571

Maxillary sinus. See *Sinus, maxillary*.

Maxillofacial fractures. See *Fractures*.

Median palatal cyst, 1957: Nov., 701

Medical case-finding by dentist, 1958: July, 283-296

Medication, systemic, dental significance, 1958: July, 297-308

Melanoma, 1957: Nov., 645, 668, 676; 1958: July, 330

Menstruation, hemorrhage and, 1957: July, 361

Meperidine, 1958: March, 70-72, 256, 268

Mephate, 1958: March, 20

Mephenesin, 1958: March, 20, 266

Mephyst, 1958: July, 340

Meprobamate, 1958: March, 19, 254

Mepylcaine, 1958: March, 45, 47

Mercaptan base impression materials, 1957: March, 157-166; 1958: Nov., 681, 685-697, 699-711

Mercurial diuretics, 1958: July, 291, 303

Mercurialism, 1958: July, 291

Mercury, sensitivity in dentists, 1958: July, 475

Mesenchymal tumors, 1957: Nov., 635

Metabutethamine, 1958: March, 45, 46

Metallic oxide pastes as impression materials, 1958: Nov., 673-675

Metastatic cancer, 1957: Nov., 729, 741

Methadone, 1958: March, 70-72, 256, 268

Methamphetamine, 1958: July, 307

Methantheline bromide, 1958: March, 267

Methprylon, 1958: March, 254

Methyl methacrylate as restorative material, 1957: March, 78-80, 107-122

Meticortelone, 1958: March, 219

Meticorten, 1958: March, 219

Metycaine, 1958: March, 45

Microbiology of oral cavity, 1958: March, 77-89; July, 309-324

Microcephalus, 1958: July, 483

Migraine, 1957: July, 473

Miltown, 1958: March, 19

Mixed odontoma, 1957: Nov., 715-717

Mixed tumor, 1957: Nov., 629, 631, 642, 657-659, 665, 673

Modeling plastic, 1958: Nov., 675-677

Mongolism, 1958: July, 484

Moniliaisis, 1957: July, 507; 1958: March, 83, 104, 141, 191; July, 375, 377, 391

Monocaine, 1958: March, 44, 46

Morphine, 1958: March, 68-71, 256

Morquio's disease, 1958: July, 482

Morson's Kreosote, 1958: March, 168

Mucocele, 1957: Nov., 665

Mucoepidermoid carcinoma, 1957: Nov., 629, 632, 642, 671; 1958: July, 333

Mucosa, oral, allergic manifestations, 1958: March, 231-243

dermatologic disease in, 1958: March, 185-193

in complete denture prosthesis, 1957: March, 189-194

in nutritional deficiency, 1958: July, 437

in pregnancy, 1957: July, 422

tumors, 1957: Nov., 661-668

Myanesin, 1958: March, 20

Mycostatin. See *Nystatin*.

Mycotic infections, 1957: July, 507, 511

Myeloma, 1958: July, 332, 424

plasma cell, 1957: Nov., 727-729

Myleran, 1958: July, 308

Myoblastoma, granular cell, 1957: Nov., 639, 645, 650, 682

Myogenetic tumors, 1957: Nov., 645

Mysoline, 1958: July, 302

Myxedema. See *Hypothyroidism*.

Myxofibroma, 1957: Nov., 681

Myxoma, 1957: Nov., 697; 1958: July, 332

NARCOTICS, 1958: March, 68-72, 256

addiction to, 1958: March, 73, 256

federal regulations, 1958: March, 74

prescriptions, 1958: March, 268

Nasopalatine duct cyst, 1957: Nov., 700-701

Nealon technique, 1957: March, 116

Neck, biopsy, 1957: Nov., 742

metastatic cancer, 1957: Nov., 741

Needle breakage, 1957: July, 337

legal aspects, 1957: July, 596

prevention, 1957: July, 497

Nembutal, dosages, 1958: March, 10, 13, 14

Neomycin in gingival and periodontal lesions, 1958: March, 103 in prevention of subacute bacterial endocarditis, 1958: March, 134

Neoplasms and "precancerous" lesions of oral regions, 1957: Nov., 621-626

Neraval sodium, 1958: March, 63

Nervous system emergencies in general anesthesia, 1957: July, 347

Neuralgia, 1957: July, 469-473; 1958: March, 34

Neurilemmoma, 1957: Nov., 639, 644, 649, 700

Neurinoma. See *Neurilemmoma*.

Neuritis, 1958: March, 34

Neurofibroma, 1957: Nov., 644, 648, 649, 675

Neurofibrosarcoma, 1957: Nov., 644

Neurogenic tumors, 1957: Nov., 635, 644, 667, 675, 682, 699

Neuroma, 1957: Nov., 644, 682 traumatic, 1957: Nov., 699

Neutropenia, malignant. See *Agranulocytosis*.

Nevi, 1957: Nov., 645, 676; 1958: July, 330

Niacin deficiency, gingivae in, 1958: July, 436

Nickel, sensitivity in dentists, 1958: July, 475

Nitrogen mustard, 1958: July, 308

Nitroglycerin medication, 1958: July, 303

Nitrous oxide-oxygen anesthesia, 1958: March, 57 in heart disease, 1957: July, 414 in pregnancy, 1957: July, 427

Non-balanced occlusion, 1957: March, 322

Non-pressure technique for resin restorations, 1957: March, 116-118

Non-zinc amalgam, 1957: March, 89

Nordefrin in local anesthetics, 1958: March, 43

Nose, disease, 1958: July, 387

Novocain. See *Procaine*.

Nucleocidin, 1958: March, 257

Nutrition and diet in edentulous patient, 1957: March, 219, 285-298

Nutritional disturbances, oral manifestations, 1958: July, 390, 429-440

Nutritional supplements in periodontal disease, 1958: March, 139

Nystatin in moniliasis, 1958: March, 104, 141, 192, 258

OBTURATION of root canal, 1957: March, 180-183; Nov., 855-871

Occlusion, concepts of, 1957: March, 322-325 determination in fractures, 1957: July, 567 posterior, choice of, 1957: March, 203-213 relation to prosthodontics, 1957: March, 313-325

Occupational diseases of dentists, 1958: July, 471-480

Ocular disease in dentists, 1958: July, 476

Odontectomy, hemorrhage in, 1957: July, 354

Odontoameloblastoma, 1957: Nov., 711, 712

Odontogenic cysts, 1957: Nov., 703-705

Odontogenic fibroma, 1957: Nov., 714, 715

Odontogenic tumors, 1957: Nov., 709-719

Odontoma, composite (mixed), 1957: Nov., 715-717

Oncocytoma, 1957: Nov., 630

Open bite, etiologic factors, 1957: March, 269-283

Operative dentistry, new developments in, symposium, 1957: March, 1-184

Opiates, 1958: March, 68-71. See also *Narcotics*.

Oracaine, 1958: March, 45, 47

Oral and systemic disease, interrelationship, symposium, 1958: July, 277-531

Oral cancer, treatment, 1957: Nov., 733-742

Oral flora, alteration of, 1958: March, 77; July, 311 common components, 1958: March, 78-85; July, 309 in healthy organism, 1958: July, 309-312 in sick organism, 1958: July, 312 suppression and superinfection, 1958: July, 311

Oral habits in etiology of open bite, 1957: March, 274-279

Oral mucosa. See *Mucosa, oral*.

Oral surgery, bleeding rate in, 1957: July, 353 blood loss in, 1957: July, 352 hemorrhage in, 1957: July, 349-365 in diabetes, 1958: July, 467-469

Oral surgery, in heart disease, 1957: July, 405-415; 1958: July, 341-345. See also under *Heart disease*.
Instrument accidents in. See *Instrument accidents*.
Orthodontics, systemic diseases of interest, 1958: July, 489-496
Orthopedic problems of dentists, 1958: July, 477
Ossifying fibroma, 1957: Nov., 681
Osteitis, alveolar, 1957: July, 533-545 deformans, 1958: July, 422
Osteogenesis imperfecta, 1958: July, 420, 482
Osteoma, 1957: Nov., 677, 682, 698 osteoid, 1957: Nov., 699
Osteomalacia, 1958: July, 421
Osteomyelitis, 1957: July, 528-529
Osteopetrosis, 1958: July, 423
Osteoporosis, 1958: July, 420
Osteosarcoma, 1957: Nov., 722-723; 1958: July, 331
Osteosclerosis, 1958: July, 482
Oxidized cellulose, 1958: March, 201
Oxycephalia, 1958: July, 484
Oxygen for emergency use, 1958: July, 521, 522-523
Oxytetracycline, 1958: March, 118 in cavity medication, 1958: March, 175
in gingivitis, 1958: March, 140
in postgingivectomy packs, 1958: March, 103
in prevention of subacute bacterial endocarditis, 1958: March, 130; July, 364, 367

PACHYDERMA oris, 1957: Nov., 623, 640
Paget's disease, roentgenographic manifestations, 1958: July, 422
Pain, dental, etiology and nature, 1958: March, 25-36
facial, 1957: July, 463-480
of dental origin, 1957: July, 463-466; Nov., 775-787
prescriptions for control of, 1958: March, 267-268
Palatal mucosa in nutritional deficiency, 1958: July, 437
Palate, tumors, 1957: Nov., 669-678
Pancreas, disorders, 1958: July, 407-409
Papillary cystadenoma lymphomatosum, 1957: Nov., 629-630
Papillary hyperplasia, 1957: Nov., 624
Papilloma, 1957: Nov., 638, 639, 647, 648, 662, 663, 669, 679, 680
Paradoxical motion, 1957: July, 587
Para-monochlorophenol in endodontics, 1957: Nov., 827; 1958: March, 155
Parathyroid glands, disorders, 1958: July, 400-402. See also *Hyperparathyroidism* and *Hypoparathyroidism*.
Patch tests for hypersensitivity, 1957: July, 444
PBSC, 1958: March, 158
Pediatric diseases of interest to dentist, 1958: July, 481-488
Pellagra, 1957: March, 290-291
Pemphigus, 1957: July, 512, 513; 1958: March, 189, 221; July, 373-375
Penicillin, allergy to, 1958: March, 238; July, 299
in cavity medication, 1958: March, 175
in fulminating gingivitis, 1958: March, 103
in prophylaxis of bacteremias, 1958: March, 129-133; July, 337-339, 365-369
in root canal medication, 1957: Nov., 828-831
systemic therapy with, 1958: March, 112-116
Penicillin V, 1958: March, 257, 268; July, 365, 368, 369
Pentobarbital, dosages, 1958: March, 10, 13, 14, 265
Pentothal. See *Thiopental*.
Periapical abscesses. See *Abscesses*.
Periapical infections, streptococci in, 1958: March, 78-79
Periapical pathosis, pain from, 1957: Nov., 780-782
Periarteritis nodosa, 1958: March, 222, 235
Pericemental abscesses. See *Abscesses*.
Pericoronal abscesses. See *Abscesses* and *Pericoronitis*.
Pericoronitis, 1957: July, 481-488, 522
Periodontal cyst, 1957: Nov., 705
Periodontal disease as factor in bacteremia, 1958: March, 126; July, 359
drugs in, 1958: March, 137-145
in pregnancy, 1957: July, 419-322
infection in, 1958: July, 314
microorganisms in, 1958: March, 86
topical antibiotics in, 1958: March, 102-104

Periodontal involvements, apical, 1957: March, 171-172, 175

Periodontal packs, 1958: March, 142

Periodontia, sedation in, 1958: March, 143

Personality factor in denture appearance, 1957: March, 249-251, 261-267

Pethidine. See *Meperidine*.

Petriclormal, 1958: March, 254

Pharyngitis, 1958: July, 393

Phenacetin. See *Acetophenetidin*.

Phenaglycodol, 1958: March, 19

Phenergan, 1958: March, 18

Phenol in cavity medication, 1958: March, 167; Nov., 589

in endodontics, 1957: Nov., 827, 828; 1958: March, 153

Phenolate in cavity medication, 1958: March, 168

Phenoxyethyl penicillin, 1958: March, 257, 268; July, 365, 368, 369

Phosphoric acid in cavity medication, 1958: March, 172

Physical examination of patient, 1958: July, 518-520

Pin fixation in mandibular fractures, 1957: July, 455

Pituitary disorders, oral effects, 1958: July, 402-405, 481-484. See also *Hypopituitarism*.

Placebo reactors, 1958: March, 213, 255

Plaque formation, 1958: March, 86

Plasma cell myeloma, 1957: Nov., 727-729

Plasmacytoma, 1957: Nov., 652, 688; 1958: July, 332

Plaster and stone, 1958: Nov., 672, 727-735

Pleomorphic adenoma. See *Mixed tumor*.

Pneumothorax, 1957: July, 585, 587

Podiatric problems of dentists, 1958: July, 477

Polyantibiotic pastes in endodontics, 1958: March, 158-160

Polymyxin B in gingival and periodontal lesions, 1958: March, 103

in prevention of subacute bacterial endocarditis, 1958: March, 134

Pontocaine, 1958: March, 44

Porcelain and plastic set-up, staggered, in denture construction, 1957: March, 267

Porcelain veneers, fused, 1958: Nov., 663-669

Posterior occlusion, choice of, 1957: March, 203-213

Postmenopausal state, roentgenographic manifestations, 1958: July, 420

Postpalatal seal in dentures, 1957: March, 228

"Precancerous" lesions, 1957: Nov., 623-625, 666-667

Prednisolone, 1958: March, 219

Prednisone, 1958: March, 219

Pregnancy, dental roentgenography in, 1957: July, 428

dental treatment in, 1957: July, 417-429

hemorrhage and, 1957: July, 361

oral mucosa in, 1957: July, 422

stress in, 1957: July, 423-424

tongue lesions in, 1957: July, 423

Pregnancy gingivitis, 1957: July, 419-420

Pregnancy tumors (gingival), 1957: July, 421-422; Nov., 686

Premedication of dental patient, 1958: March, 3-23; July, 520

for prevention of subacute bacterial endocarditis, 1958: March, 119-136

Preoperative medication, 1958: March, 3-23

Preoperative sedation, prescriptions for, 1958: March, 265-266

Preparation of cavities. See *Cavity preparation* and *High speed*.

Prescription writing, 1958: March, 261-269

Pressure technique for resin restorations, 1957: March, 113-116

Preventive medical case-finding, 1958: July, 283-296

Prinacaine, 1958: March, 45, 47

Primary aldosteronism, 1958: July, 407

Primidone medication, 1958: July, 302

Primordial cyst, 1957: Nov., 703

Pro-Banthine, 1958: July, 307

Procaine, 1958: March, 44-46

hypersensitivity, 1958: March, 237

in dentists, 1958: July, 474

hormonal therapy, 1958: March, 221

tests, 1957: July, 443

Procaine amide, 1958: July, 303

Prochlorperazine, 1958: March, 18

Promazine, 1958: March, 18

Promethazine, 1958: March, 18

Prophylaxis, airbrasive technique, 1957: March, 47

Propoxyacaine, 1958: March, 44, 47

Prosthesis, dental, postsurgical, 1957: Nov., 743-748
facial, 1957: Nov., 749-758

Prosthodontic needs, differential diagnosis of, symposium, 1957: March, 185-325

Protamine sulfate in hemostasis, 1958: March, 207; July, 340

Protein deficiency, roentgenographic manifestations, 1958: July, 420

Proteinuria, tests, 1958: July, 464

Prothrombin time, 1957: July, 351

Pseudocheilosis, 1958: July, 431

Pulp, normal, 1957: March, 168

Pulp capping and pulp amputation, 1957: Nov., 789-804

Pulp stones as cause of pain, 1957: July, 464

Pulp tests, 1957: Nov., 783-785

Pulpal hyperemia, 1957: March, 169; July, 465; 1958: March, 96

Pulpal necrosis, 1957: March, 170, 174; July, 465

Pulpal pathosis, pain from, 1957: July, 463-466

Pulpal response to airabrasive technique, 1957: March, 49
to orthophosphoric acid, 1957: March, 87
to self-curing resins, 1957: March, 79, 118
to silicate cement, 1957: March, 77

Pulpectomy, 1957: March, 176; Nov., 798

Pulpitis, 1957: March, 170, 173; July, 465; Nov., 778-780

Pulpless tooth. See *Endodontics and Tooth, pulpless*.

Pulpotomy, 1957: Nov., 798

Purinethol, 1958: July, 308

Purpura, thrombocytopenic, 1957: July, 358

Pyogenic granuloma, 1958: July, 378

Pyribenzamine, 1958: July, 306

Pyridium, allergy to, 1958: March, 238

Pyroglossia, 1957: July, 516, 517

Pyrrobutamine compound, 1958: March, 212

QUINIDINE, 1958: July, 303

RADIATION hazard to dentists, 1958: July, 472-474

Radiation injury, 1957: July, 505

Radiation therapy in oral cancer, 1957: Nov., 735

Ranulas, 1957: July, 530

Rauwolfia compounds, 1958: March, 18, 253; July, 341

Ravocaine, 1958: March, 44, 47

Reserpine, 1958: March, 253

Resin veneers, 1958: Nov., 654-663

Resins in prosthetic dentistry, 1958: Nov., 593-602
self-curing, 1957: March, 78-80, 102-122; Nov., 887; 1958: Nov., 587, 603-614

Respiratory emergencies. See also *Airway obstruction*.
in general anesthesia, 1957: July, 343-346

Respiratory insufficiency, 1957: July, 584-587

Rest position, 1957: March, 316

Restorations. See also under specific type, e.g., *Amalgam*.
coronal, of treated pulpless tooth, 1957: Nov., 885-896

Restorative materials, selection for operative dentistry, 1957: March, 65-80. See also specific materials, e.g., *Amalgam*.

Resuscitation in emergencies, 1958: July, 515-526

Reticulendotheliosis, 1958: July, 424-425

Reticulum cell sarcoma, 1957: Nov., 727, 739; 1958: July, 331

Retinal detachment, 1958: July, 528

Rhabdomyoma, 1957: Nov., 645, 651, 652

Rhabdomyosarcoma, 1957: Nov., 645, 652; 1958: July, 330

Rheumatoid temporomandibular joint, hormonal therapy, 1958: March, 220

Rhinitis, allergic, 1958: March, 234

Riboflavin deficiency, lips in, 1958: July, 430

Rickets, oral manifestations, 1958: July, 418, 438, 483

Ristocetin, 1958: March, 257

Roentgenographic manifestations, oral, of systemic disease, 1958: July, 413-427

Roentgenography in location of foreign bodies, 1957: July, 339-401
in pregnancy, 1957: July, 428
in sinusitis, 1957: July, 467-469

Root canal sealers, 1957: Nov., 871

Root canal therapy. See *Endodontics*, and under *Pulp*.

Root fractures, 1957: July, 372-373

Root fragments, removal, 1957: July, 379-390
 retention, 1957: July, 495-497
 roentgenographic differentiation, 1957: July, 379-380

Root resection and apical curettage, 1957: Nov., 873-883

Rotating instruments, modern, 1958: Nov., 737-745. See also under *High speed*.

Rubber base impression materials, 1957: March, 157-166; 1958: Nov., 681, 685-697, 699-711

Rubber dam, 1957: March, 48, 89

Rule of nines in burns, 1957: July, 589

Rutin in hemostasis, 1958: March, 209

SALICYLAMIDE, 1958: March, 21, 255

Salicylates, 1958: March, 21

Saliva as factor in denture retention, 1957: March, 200

Salivary glands, infections, 1957: July, 531
 inflammations, 1957: July, 529-531
 tumors, 1957: Nov., 627-636, 642, 665, 673-675, 1958: July, 333

Salivation, control of, 1958: March, 267; July, 307

Sarcoma, Ewing's, 1957: Nov., 726; 1958: July, 331
 neurogenic, 1957: Nov., 675
 osteogenic, 1957: Nov., 722
 reticulum cell, 1957: Nov., 727; 1958: July, 331
 treatment, 1957: Nov., 739

Sarcosinate dentifrices, 1958: March, 182

Schwannoma. See *Neurilemmoma*.

Scleroderma, 1958: March, 222

Scopolamine, 1958: March, 21

Scratch tests for hypersensitivity, 1957: July, 443

Scurvy, 1957: March, 295; 1958: July, 435, 438, 488

Secobarbital, 1958: March, 10, 13, 14, 266

Seconal. See *Secobarbital*.

Sedation, 1958: March, 8-15, 143, 253, 265-266
 for children, 1957: July, 368

Senility, roentgenographic manifestations, 1958: July, 420

Sensitivity reactions, 1957: July, 441-450. See also *Allergy* and *Hypersensitivity*.

Sensitivity tests, 1958: March, 111

Serpasil, 1958: March, 18, 253

Serum sickness, 1958: March, 233

Sex factor in denture appearance, 1957: March, 249, 261-267

Shingles, 1958: March, 191

Shock, 1957: July, 431-439, 587-588.
 See also *Hypersensitivity*.

surgical, in heart disease, 1957: July, 409

Sialoliths, 1957: July, 530

Silicate cements, 1957: March, 75-78; 1958: Nov., 563-569

cavity liners under, 1958: Nov., 585
 cavity preparation for, 1957: March, 13

Silicone base impression materials, 1958: Nov., 682, 685-697

Silicosis as hazard to dentists, 1958: July, 476

Silver cones in root canal obturation, 1957: March, 183; Nov., 864-871

Silver nitrate in cavity medication, 1958: March, 170-172

Sinus, maxillary, accidental opening, 1957: July, 526, 573-577
 diseases, 1958: July, 387-390
 infections, 1957: July, 526-528
 root fragments, 1957: July, 387-389

Sinusitis, pain from, 1957: July, 466-469

Skin diseases, 1958: March, 185-193; July, 371-380

Skin tests for hypersensitivity, 1957: July, 443-444

Sliding flap technique in antral-oral fistula, 1958: July, 389, 390

Snake venom in hemostasis, 1958: March, 208

Snyder test, 1958: March, 81

Socket, dry. See *Osteitis, alveolar*.

Sodium fluoride in cavity medication, 1958: March, 172
 in dentifrices, 1958: March, 183

Sodium Pentothal. See *Thiopental*.

Soldering procedures, gold, 1958: Nov., 747-757
 stainless steel, 1958: Nov., 778

SPA factors in denture appearance, 1957: March, 249-252, 261-267

Spacer trays, 1957: March, 222-223

Sparine, 1958: March, 18

Spastic patients, prescriptions for, 1958: March, 266

Spherical occlusion, 1957: March, 322

Spirochetes in oral cavity, 1958: March, 82; July, 310

Squamous cell. See *Carcinoma, Epithelioma, Papilloma*.

Stainless steels, 1958: Nov., 773-788
Stannous fluoride in dentifrices, 1958:
 March, 183
Starch sponge, 1958: March, 204
Steel, stainless, 1958: Nov., 773-788
Steeple head, 1958: July, 484
Stellite alloys, 1958: Nov., 759-771
Sterilization in endodontics, 1957:
 Nov., 838-840; 1958: March,
 151-163
 of cavity, 1957: March, 87
 of operative site in reduction of
 bacteremias, 1958: March, 123
Stevens-Johnson syndrome, 1957: July,
 512; 1958: July, 372
Stomatitis, 1957: July, 531
 aphthous, 1957: July, 515-516;
 1958: July, 372, 374
 diabetic, 1957: July, 516
 herpetic, 1958: July, 372
 medicamentosa, 1957: July, 514;
 1958: July, 372, 374
 necrotizing, 1957: July, 506
 nonspecific, 1957: July, 505
 venenata, 1957: July, 515; 1958:
 July, 379
Stone and plaster, 1958: Nov., 672,
 727-735
Strength of materials, 1958: Nov.,
 792-794
Streptococci in caries, 1958: March, 79
 in root canal and periapical infec-
 tions, 1958: March, 78-80
 in subacute bacterial endocarditis,
 1958: March, 79; July, 362
Streptomycin in cavity medication,
 1958: March, 175
 in prevention of subacute bacterial
 endocarditis, 1958: March, 130,
 132
Stress in dental structures, analysis,
 1958: Nov., 789-798
 in pregnancy, 1957: July, 423-424
Subacute bacterial endocarditis. See
 Endocarditis.
Subperiosteal abscesses. See *Abscesses*.
Succinylcholine, 1958: March, 62
Sudsing agents in dentifrices, 1958:
 March, 180
Sugar, urine tests, 1958: July, 463
Sulfamic acid activation of resins, 1957:
 March, 108
Sulfonamides in cavity medication,
 1958: March, 174
Surgery, oral. See *Oral surgery*.
Surgical cleanliness in endodontics,
 1957: Nov., 835-844
Surgical dressings in periodontal thera-
 py, 1958: March, 142
Surgical management of oral cancer,
 1957: Nov., 734
Swallowing, abnormal, as cause of
 open bite, 1957: March, 274-279
Syncope, 1957: July, 336, 433; 1958:
 July, 516
 in circulatory collapse, 1957: July,
 434-435
Syphilis, 1958: March, 87
 as hazard to dentists, 1958: July,
 479
 oral manifestations, 1957: July, 510;
 1958: July, 373, 374, 378, 418,
 483, 487
Systemic and oral disease, interrela-
 tionship, symposium, 1958: July,
 277-531
Systemic diseases of children, 1958:
 July, 481-488
 of interest to orthodontist, 1958:
 July, 489-496
 oral roentgenographic manifesta-
 tions, 1958: July, 413-427
Systemic medication, dental signifi-
 cance, 1958: July, 297-308

TEETH. See also *Tooth*.
 anterior, fractures, 1957: July, 367-
 377
 discolored, bleaching, 1957: Nov.,
 897-902
 displacement, 1957: July, 373-376
 posterior, selection, 1957: March,
 211
 sensory innervation, 1958: March,
 28
 traumatized, 1957: July, 367-377
Temporomandibular joint, hydrocorti-
 sone injection, 1958: July, 386
 relation to aural symptoms, 1958:
 July, 381-387
 rheumatoid, hormonal therapy,
 1958: March, 220
Tension pneumothorax, 1957: July,
 587
Terramycin. See *Oxytetracycline*.
Tetracycline, 1958: March, 117, 269
 in gingivitis, 1958: March, 103, 140
Tetracyclines, 1958: March, 116-118;
 July, 300
 in cavity medication, 1958: March,
 175
 in prophylaxis of bacteremia, 1958:
 July, 364, 367, 369
Tetracyn. See *Tetracycline*.

Therapeutic dentifrices, 1958: March, 179-184

Thermal expansion inlay casting technique, 1957: March, 71; 1958: Nov., 637-651

Thiogenal, 1958: March, 63

Thiokol. See *Mercaptan base impression materials*.

Thiopental anesthesia, 1958: March, 59

 in heart disease, 1957: July, 414

 in pregnancy, 1957: July, 427

Thiouracil, 1958: July, 305

Thorazine, 1958: March, 16-18

Throat, diseases, 1958: July, 393-395

Thrombin, topical, in hemostasis, 1958: March, 207

Thrombocytopenic purpura, 1957: July, 358; 1958: March, 223; July, 486

Thrush. See *Moniliasis*.

Thumb sucking as cause of open bite, 1957: March, 279

Thymol in cavity medication, 1958: March, 169

Thyroid gland, disorders, 1958: July, 397-400. See also *Hyperthyroidism* and *Hypothyroidism*.

Thyroid substance, 1958: July, 305

Tic douloureux, 1957: July, 469-472

Tics, major, 1957: July, 469-473

Tinnitus, 1958: July, 386

Tissue conditioning for complete dentures, 1957: March, 217

Tofflemire matrix band, 1957: March, 92, 93

Tolonium chloride in hemostasis, 1958: March, 207

Tolserol, 1958: March, 20, 266

Tongue, acute lesions, 1957: July, 503-520. See also *Glossitis*.

 and floor of mouth, tumors, 1957: July, 518-519; Nov., 647-660

 black hairy, 1958: July, 392

 in etiology of open bite, 1957: March, 274-279

 in nutritional deficiency, 1958: July, 431-435

 in pregnancy, 1957: July, 423

 tumors, 1957: July, 518-519; 1958: July, 328, 393

Tonsil, carcinoma, 1958: July, 394

Tooth. See also *Teeth*.

 extraction as factor in bacteremia, 1958: July, 318-320, 357

 pulpless, coronal restoration, 1957: Nov., 885-896

Tooth arrangement in dentures, 1957: March, 227

 try-in, 1957: March, 239

Tooth factors in denture appearance, 1957: March, 259-267

"Toothache." See *Pain of dental origin*.

Topical anesthetics, 1958: March, 48

Torus palatinus, 1957: Nov., 677

Tourniquet(s), 1957: July, 583-584

 in anaphylactoid reactions, 1957: July, 437

Tourniquet test, 1957: July, 350

Tracheotomy, 1957: July, 345, 395-397, 585

 legal aspects, 1957: July, 598

Tranquilizers. See *Ataraxics*.

Transient bacteremias, dental, prophylaxis, 1958: July, 351-370

Transitional cell. See *Carcinoma*.

Trauma, relation to bacteremias, 1958: March, 125

Traumatic bone "cyst," 1957: Nov., 706-707

Tray technique with rubber impression material, 1958: Nov., 699-708

Treponema pallidum, 1958: March, 87

Trial denture base, 1957: March, 231-243

Trigeminal nerve, 1958: March, 28

Trigeminal neuralgia, 1957: July, 469-472

Try-in of tooth arrangement, 1957: March, 239

Tube technique with rubber impression material, 1958: Nov., 708-710

Tuberculosis, oral lesions, 1957: July, 510; 1958: March, 88; July, 378, 487

Tumors, malignant, clinical features, 1958: July, 325-333. See also specific types, e.g., *Carcinoma*.

of oral regions, symposium, Nov., 619-758. See also under structure, e.g., *Lip*; kind of tumor, e.g., *Carcinoma*; and tissue type, e.g., *Epithelial tumors*.

ULCER therapy, 1958: July, 307

Ultra speed instrumentation, 1957: March, 28, 29, 31-42; 1958: Nov., 742-744

Ultran, 1958: March, 19

Ultrasonic technique, 1957: March, 53-62

Unacaine, 1958: March, 45, 46

Unilateral hyperplasia of face, 1958: July, 417, 484

Urine tests in diabetes, 1958: July, 463

Uveitis, 1958: July, 528

VANCOMYCIN, 1958: March, 257
Varicosities in dentists, 1958: July, 478
Vascular disease in dentists, 1958:
 July, 478
Vasoconstrictors, 1958: March, 42, 44-
 45
 in hemostasis, 1957: July, 363; 1958:
 March, 206
 in resuscitation, 1958: July, 516, 524
 in shock, 1957: July, 437
 toxic effects, 1957: July, 340
Veneer preparations, high speed, 1957:
 March, 39-41
Veneered gold crown, 1958: Nov.,
 653-669
Verruca vulgaris of lip, 1957: Nov., 638
Vertical dimension, determination with
 trial denture base, 1957: March,
 235-236
 in complete denture technique,
 1957: March, 225
Vesicular dermatoses, 1957: July, 512-
 514
Vibration in high speed instruments,
 1957: March, 19-20
Vincent's infection. See *Fusospirocheto-*
 sis.
Viral infections, 1957: July, 508-510;
 1958: March, 85
Visual problems of dentists, 1958: July,
 476
Vitamin A deficiency, mucosa in, 1958:
 July, 437
Vitamin C in hemostasis, 1958: March,
 208
Vitamin K in hemostasis, 1958: March,
 207, 208
Vitamin K deficiency, gingivae in,
 1958: July, 437
Vitamin K, in hypoprothrombinemia,
 1958: July, 340
Vitamin P in hemostasis, 1958: March,
 209
Vitamins in edentulous patient, 1957:
 March, 289-295
 in periodontal disease, 1958: March,
 139
Vomiting as anesthetic emergency,
 1957: July, 348
WARTHIN's tumor, 1957: Nov., 630
Warts, 1958: July, 378
Water fluoridation, physiologic effects,
 1958: July, 441-458
Wax, inlay, 1957: March, 70
 mouth-temperature, 1958: Nov.,
 677-680
Wax pattern, 1958: Nov., 615-623,
 625-627
Wax-expansion inlay casting tech-
 nique, 1957: March, 71
Wetzel grid, 1958: July, 505-506
Wounds, extraction, retarded healing,
 1957: July, 533-545. See also
 Osteitis, alveolar.
 topical antibiotics in, 1958:
 March, 105
soft tissue, 1957: July, 452
traumatic, 1957: July, 590
XEROSTOMIA, 1957: July, 516
 from ulcer medications, 1958: July,
 307
Xylocaine, 1958: March, 45, 47
YOUNG's rule, 1957: July, 368; 1958:
 March, 263
ZINC cement cavity liner, 1958: Nov.,
 586, 587
Zinc chloride-potassium ferrocyanide
 solutions, 1958: Nov., 588
Zinc oxide-eugenol cavity liner, 1958:
 Nov., 586, 587, 590
 impression pastes, 1958: Nov.,
 673
Zinc phosphate and silicate cements,
 1958: Nov., 561-569
Zinc salts in cavity medication, 1958:
 March, 172
Zygomatic fractures, 1957: July, 456,
 563-565